Land Data Assimilation Systems at NCEP/EMC

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Outline

- Motivation
- Applications:
  - North American Land Data Assimilation System (NLDAS) -- “Flagship” LDAS project at NCEP
  - “HRAP”-NLDAS
  - Global LDAS (GLDAS)
- Methods/examples:
  - Surface emissivity/Tb assimilation
  - Soil moisture
  - Snow
- Summary/Future

Motivation

- Better initial land conditions for numerical weather prediction (NWP) and seasonal climate model forecasts, and application to regional and global drought monitoring and seasonal hydrological prediction.

- Assess model (physics) performance and make improvements by assimilating real land data (sets).

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NLDAS background

- Drought monitoring and hydrological seasonal prediction.
- Uncoupled multi-model system.
- Long-term project (2000-present & beyond).
- Multi-institution collaboration (NOAA, NASA, Princeton U, Univ Wash, NWS/OHD, others).
- Multi-agency sponsored support (i.e., NOAA/CPO GAPP, CPPA & MAPP; NASA Terrestrial Hydrology Program).
- R2O task: from research to NCEP operations.

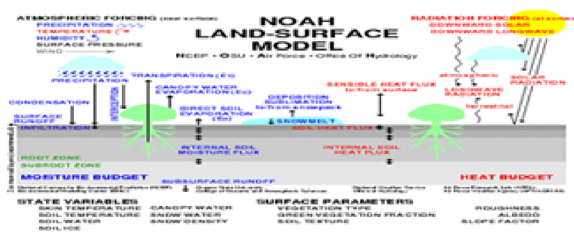
Youlong Xia and NLDAS team

- NLDAS is a multi-model land modeling and data assimil. system…
- …run in uncoupled mode driven by atmospheric forcing (using surface meteorology data sets)…
- …with *"long-term"* retrospective and near real-time output of land-surface water and energy budgets.

NLDAS Configuration: Land models

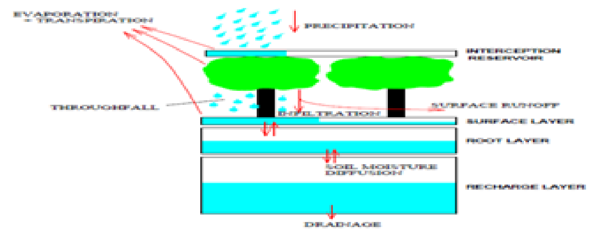
- Uncoupled ("offline") simulations.
- Input: atmospheric forcing.
- Output: water/energy budgets (surface fluxes, land states)

Atmospheric Community



Noah

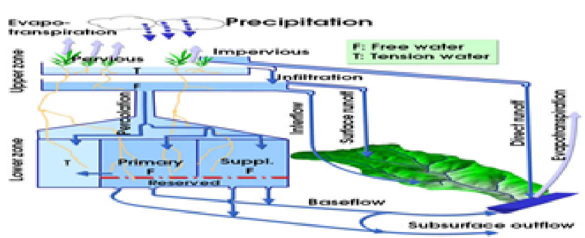
NCEP operational land model



Mosaic

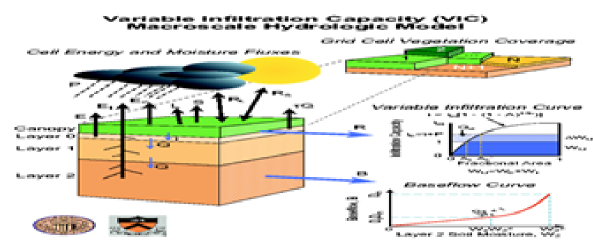
NASA GSFC

Hydrology Community



SAC

NWS operational hydrological model

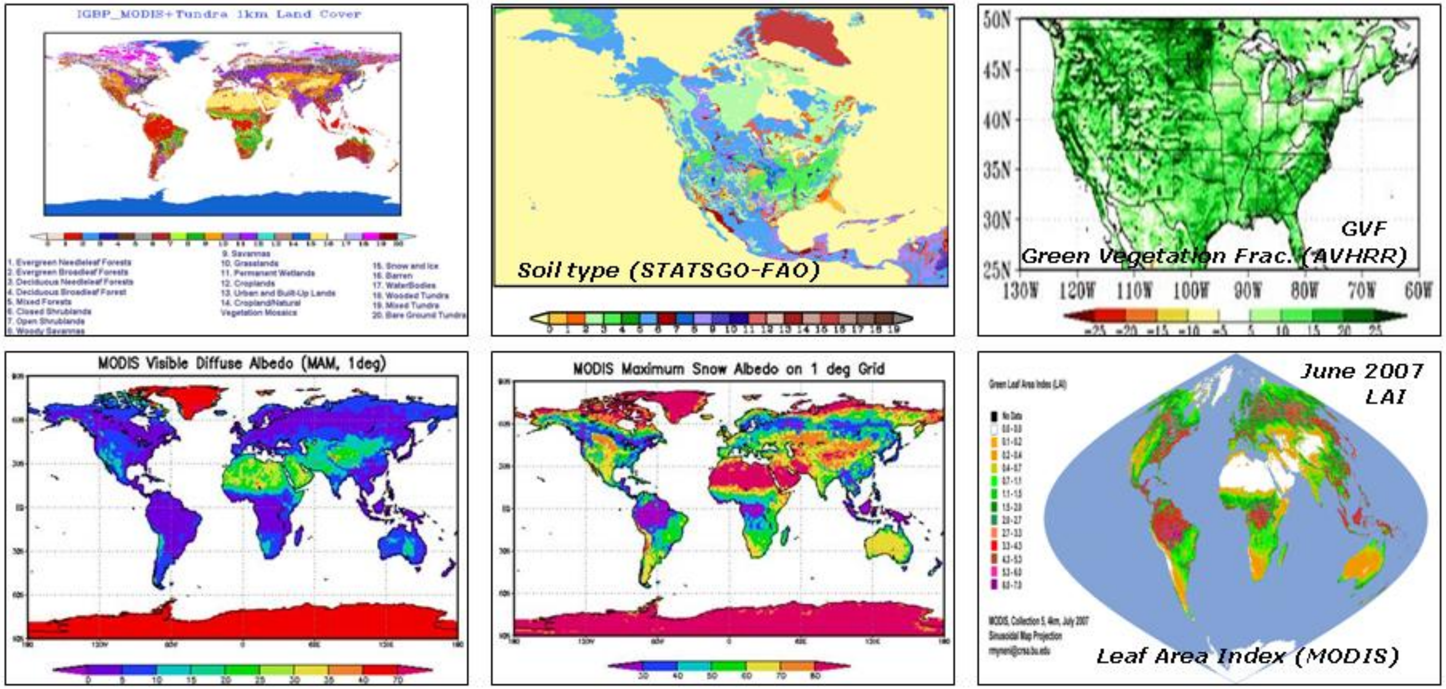


VIC

Princeton & U. Washington

NLDAS Data Sets and Setup

NLDAS Configuration: Land data sets



- **fixed climatologies** or **near real-time obs.**
- Some quantities may be **assimilated** (e.g. soil moisture, snow).

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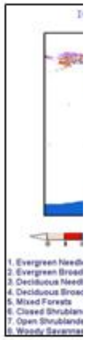
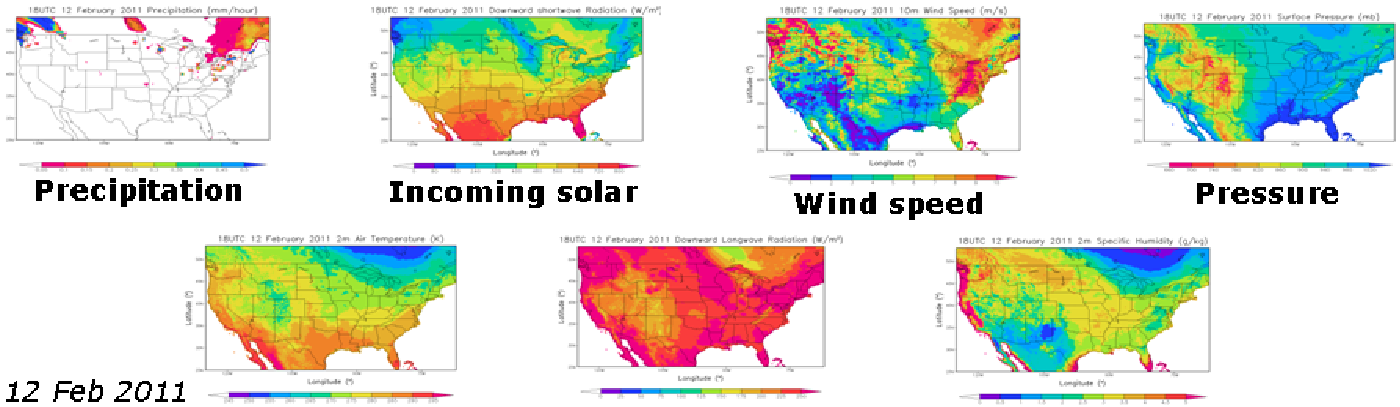
NLDAS Data Sets and Setup

NLDAS Configuration: Land data sets



NLDAS Configuration: Forcing data



- Continental US domain, 1/8th degree resolution.
- Common land surface forcing from North American Regional Reanalysis real-time extension (gauge-based observed precipitation, temporally disaggregated with radar/sat. data).
- hourly, 1/8-deg, Jan 1979 to present, near real-time.

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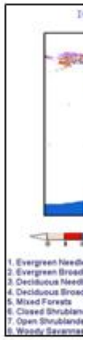
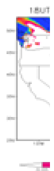
NLDAS Data Sets and Setup

NLDAS Configuration: Land data sets





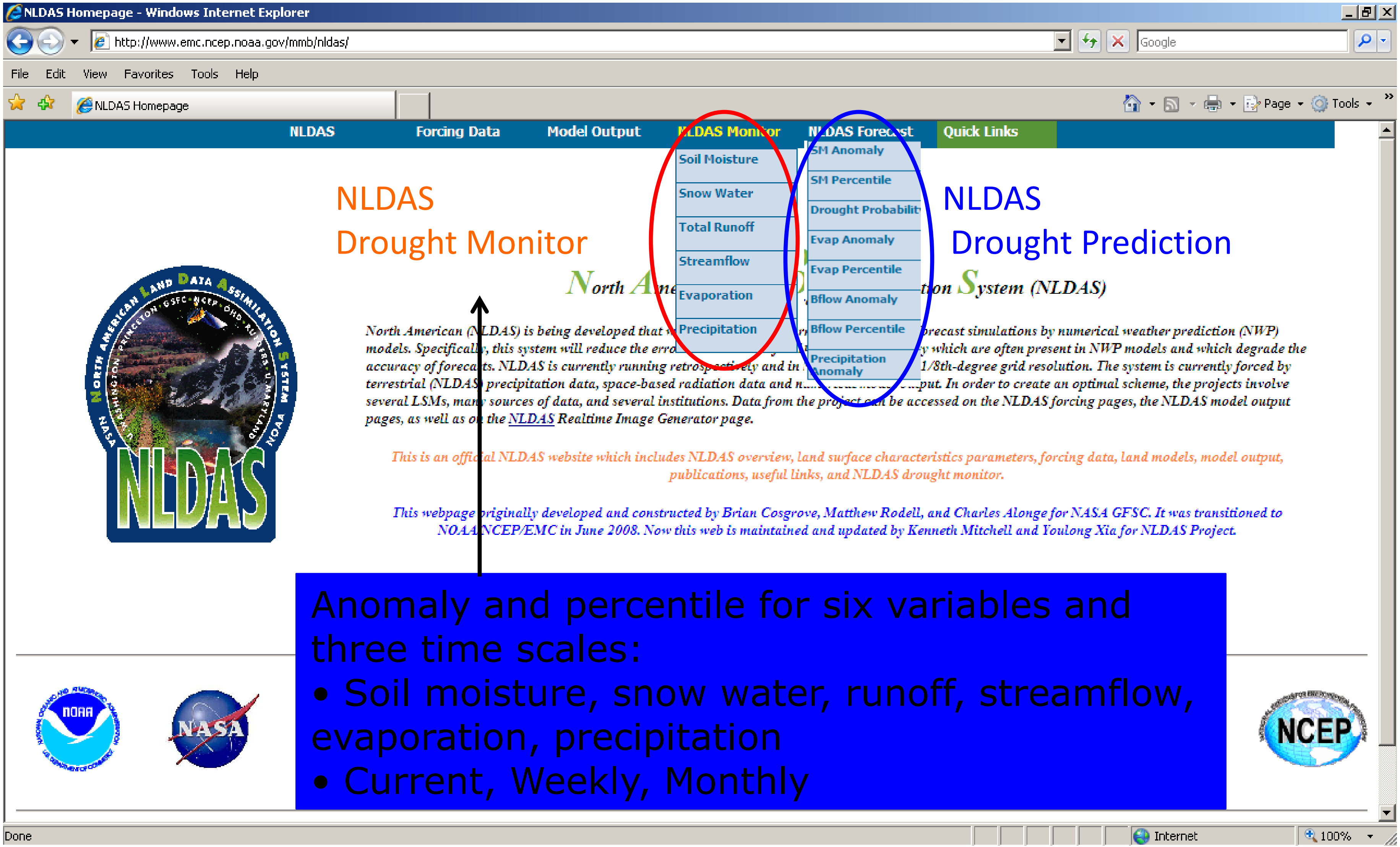
NLDAS Configuration: Forcing data

NLDAS Configuration: Simulations

- Retrospective mode (*to provide climatologies*)
  - 30-year runs: Oct 1979-Sep 2008
  - 15-year spin-up
  - 30-year climatology for each land model (1979-2008)
- Near real-time mode (*quasi-operational*)
  - depict conditions as anomalies and percentiles from climatology

NCEP-NLDAS website　　*NASA-NLDAS website*

www.emc.ncep.noaa.gov/mmb/nldas　　*ldas.gsfc.nasa.gov/nldas*



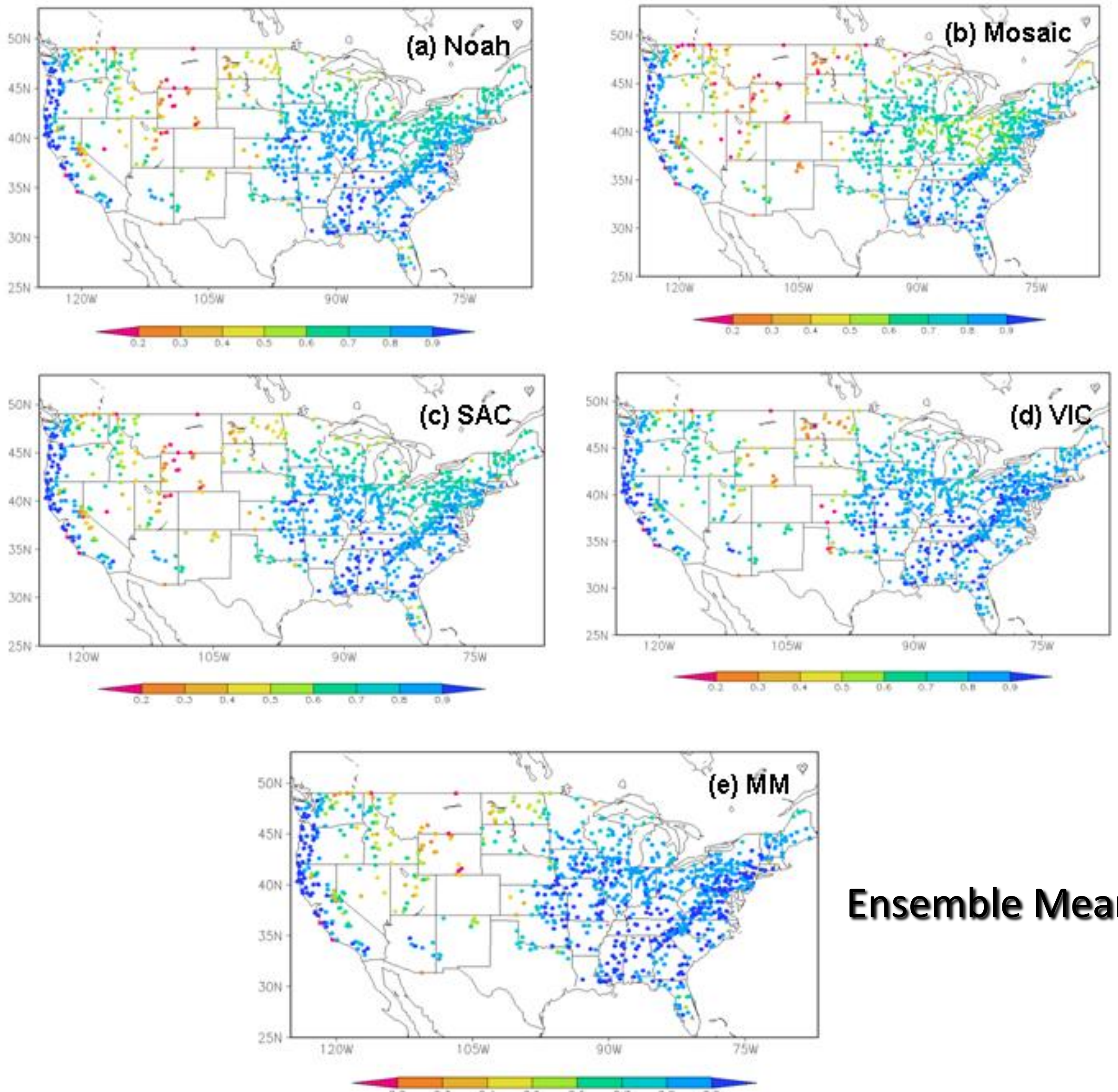
Anomaly and percentile for six variables and three time scales:

- Soil moisture, snow water, runoff, streamflow, evaporation, precipitation
- Current, Weekly, Monthly

NLDAS Evaluation and Validation

JGR, Xia et al., 2011, submitted

Monthly streamflow anomaly correlation over continental United States (1979-2007 USGS measured streamflow)



Ensemble Mean

NLDAS Evaluation and Validation

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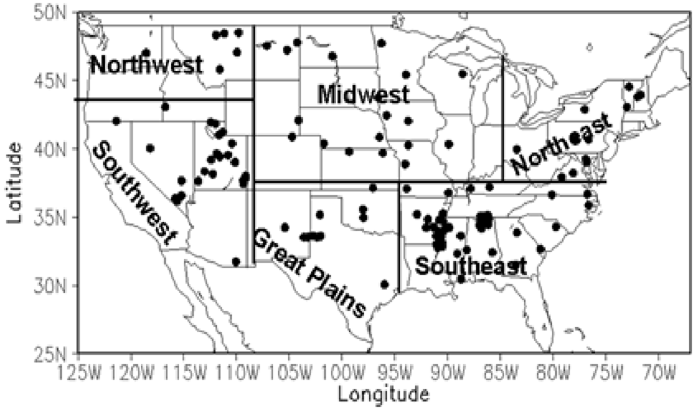
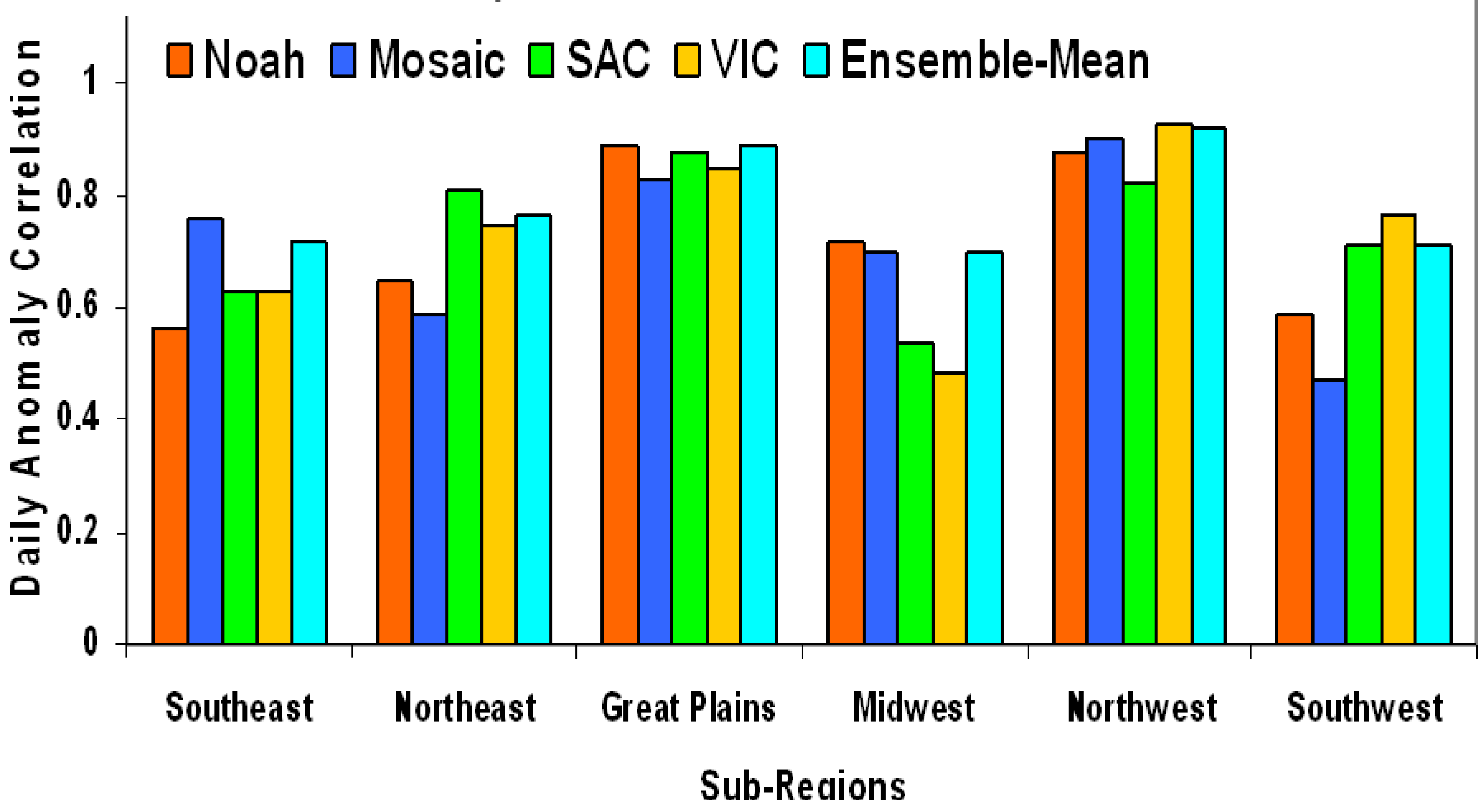


Spatial averaged daily top 1m soil moisture anomaly correlation over continental United States

U.S. Soil Climate Analysis Network (SCAN), 1 January 2002 - 31 December 2009



JHM, Xia et al., 2011, in preparation

Texas Drought 2011
Near Real-time Quasi-weekly
Texas Drought Monitoring (D0 yellow – D4 red)

Four-model ensemble mean total column soil moisture percentile
(5 January -14 September 2011)

Next slide shows
daily flood monitoring case

Texas Drought 2011
Near Real-time Quasi-weekly
Texas Drought Monitoring (D0 yellow – D4 red)

Four-model ensemble mean total column soil moisture percentile
(5 January

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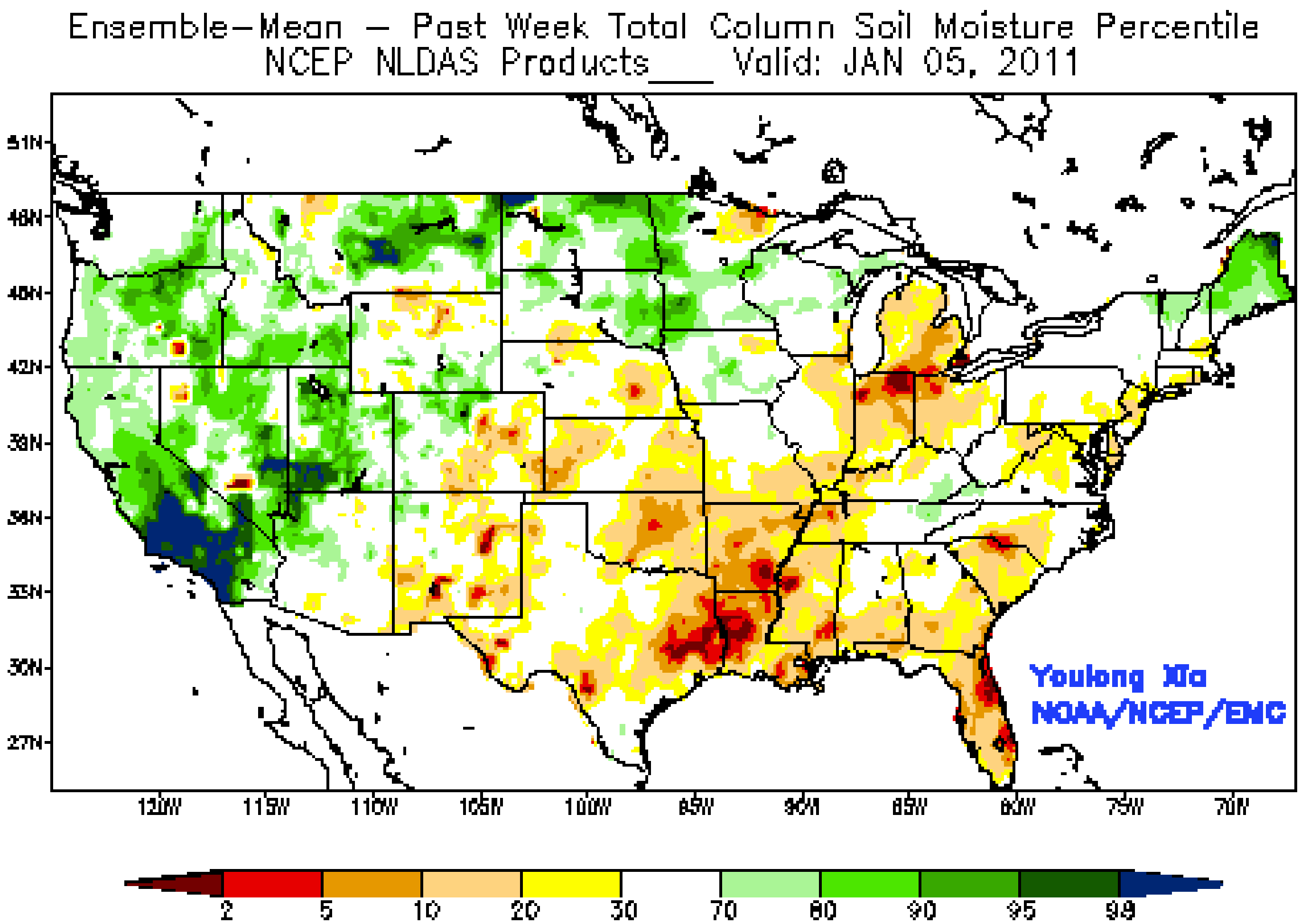

Northeast Flood 2011 Monitoring

Impact of Hurricane Irene and Tropical Storm Lee

Ensemble mean daily streamflow anomaly (m^3/s) 20 Aug – 17 Sep

NLDAS Application to
U.S. Drought Monitor (USDM) and USDA

Northeast Flood 2011 Monitoring

Impact of Hurricane Irene and Tropical Storm Lee

Ensemble mean daily streamflow anomaly (m^3/s) 20 Aug – 17 Sep

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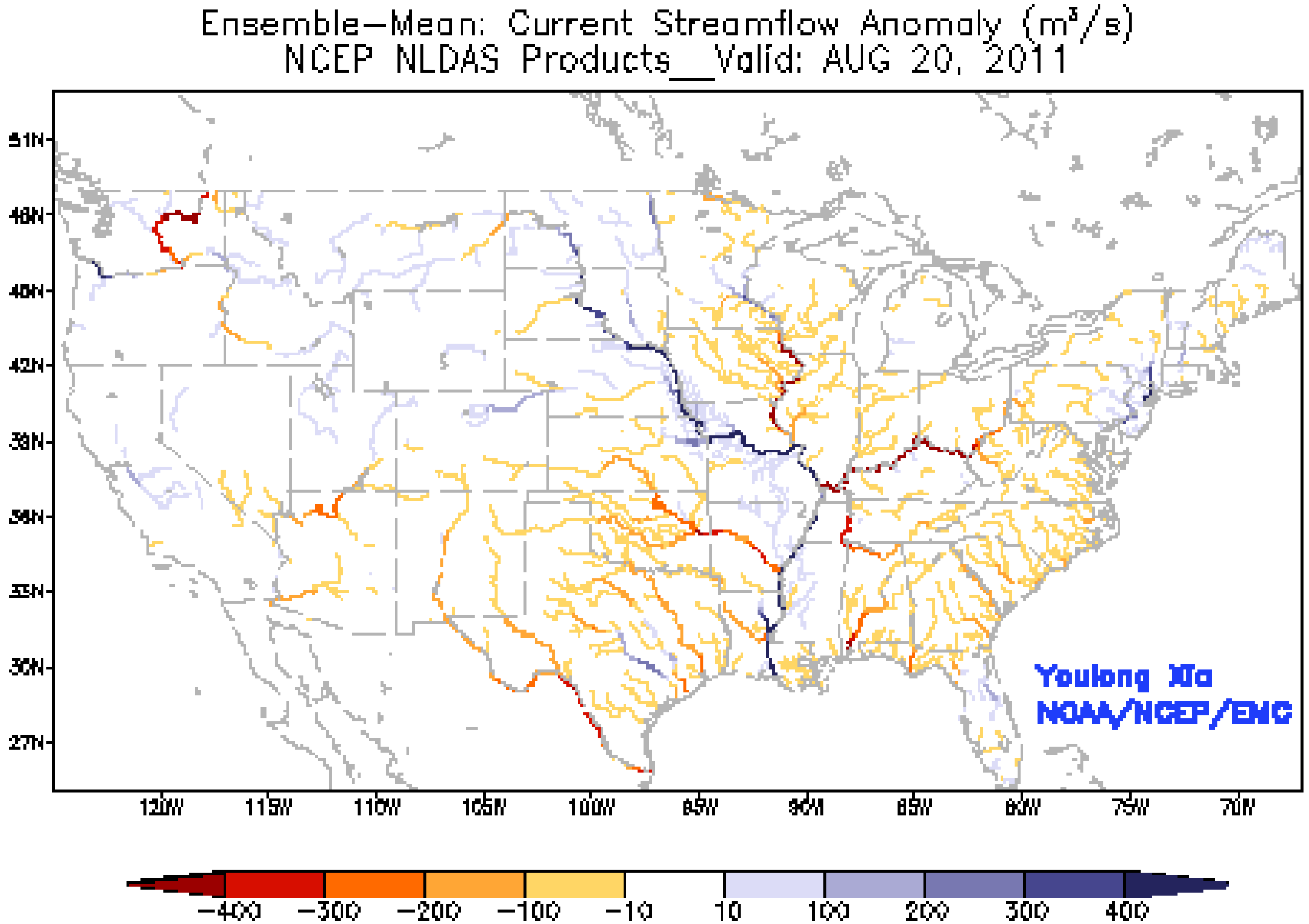
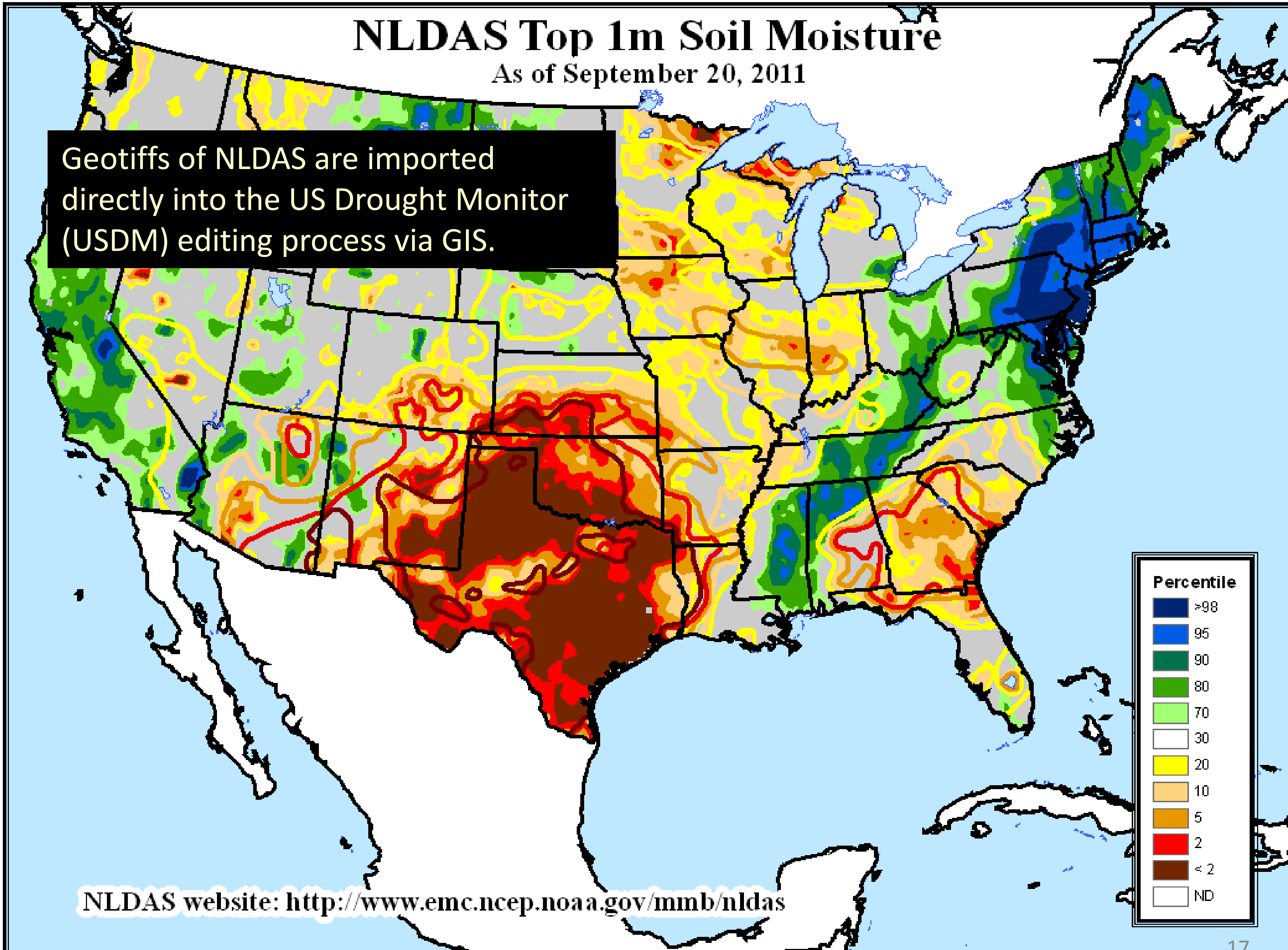
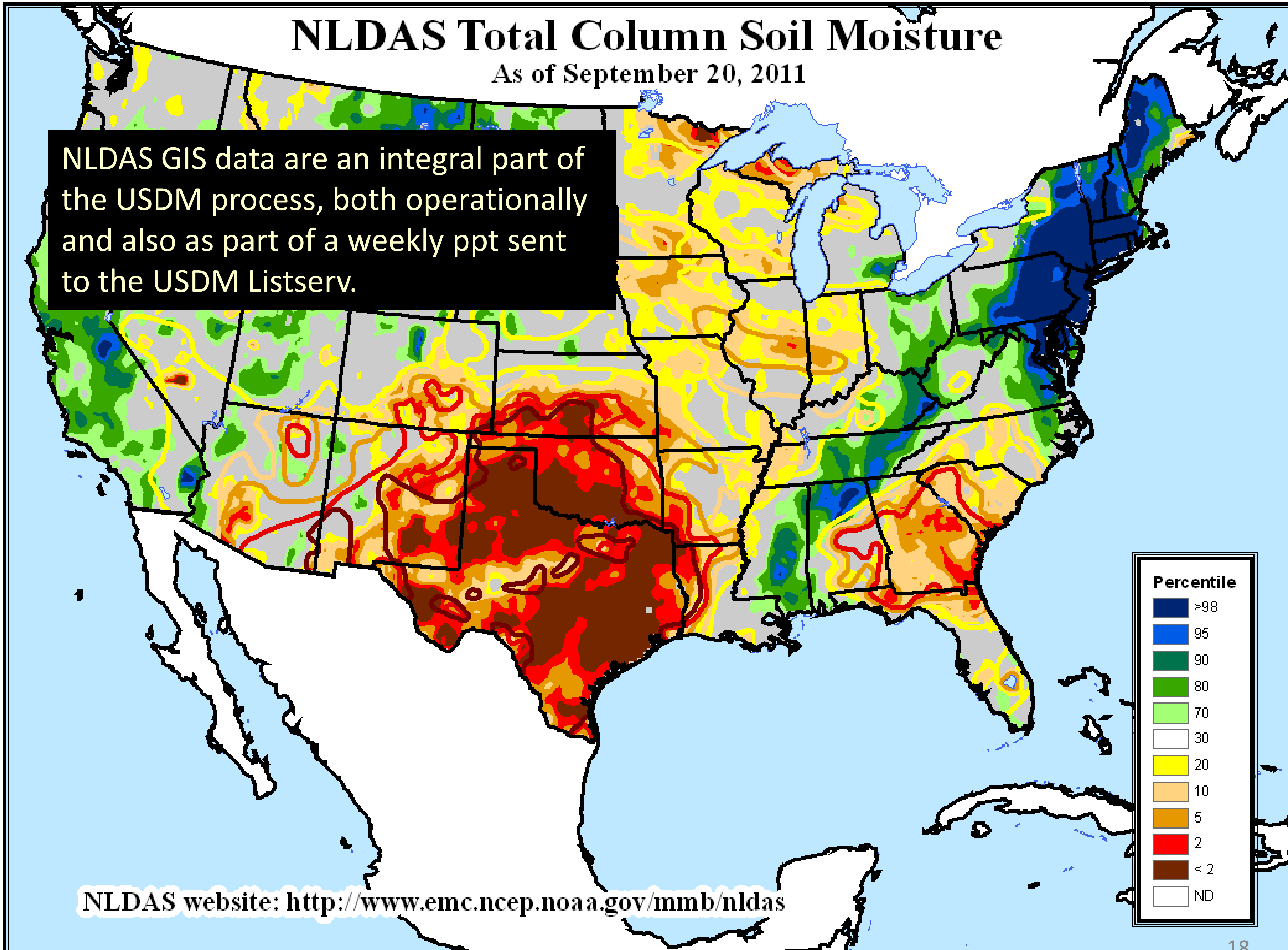
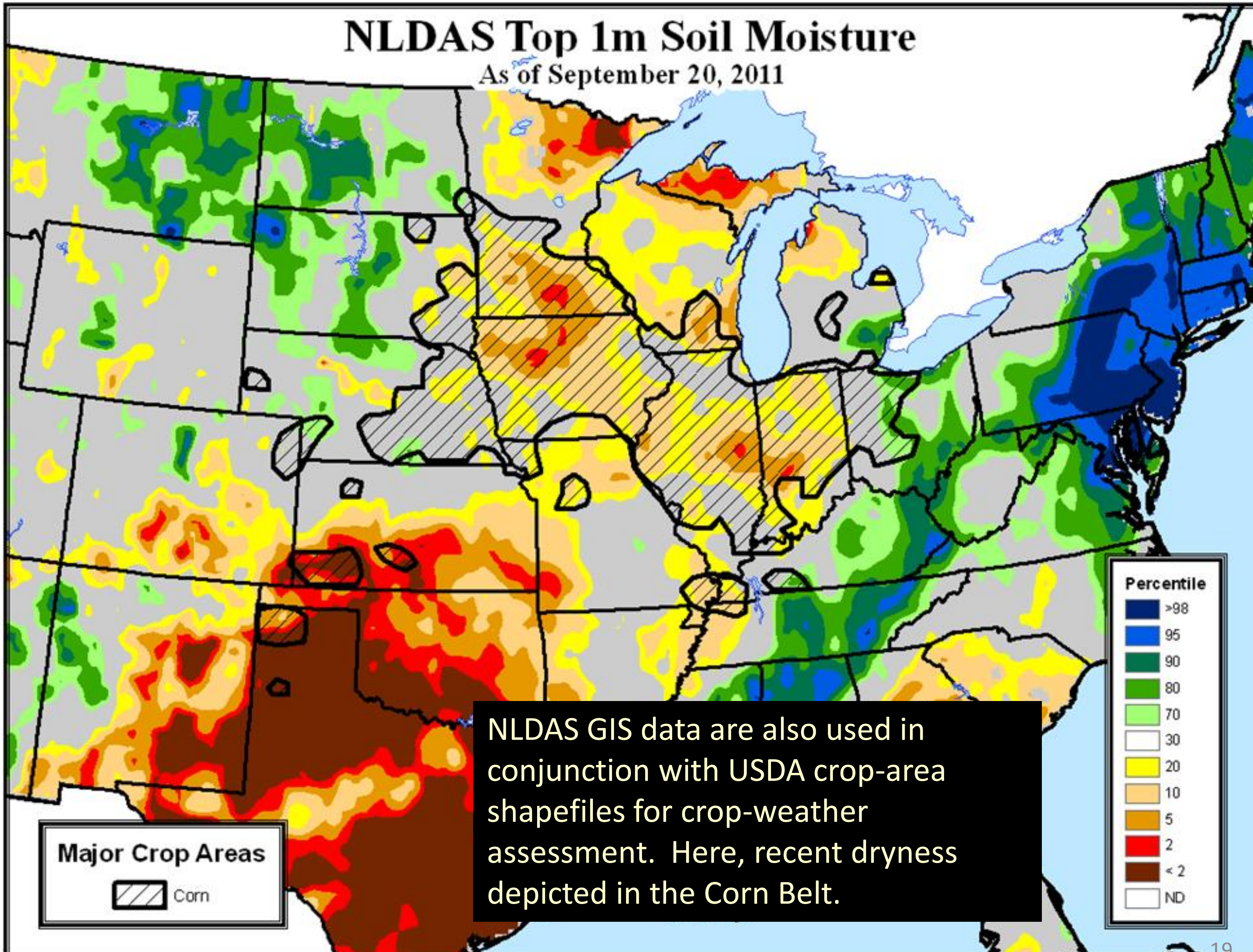
U.S.



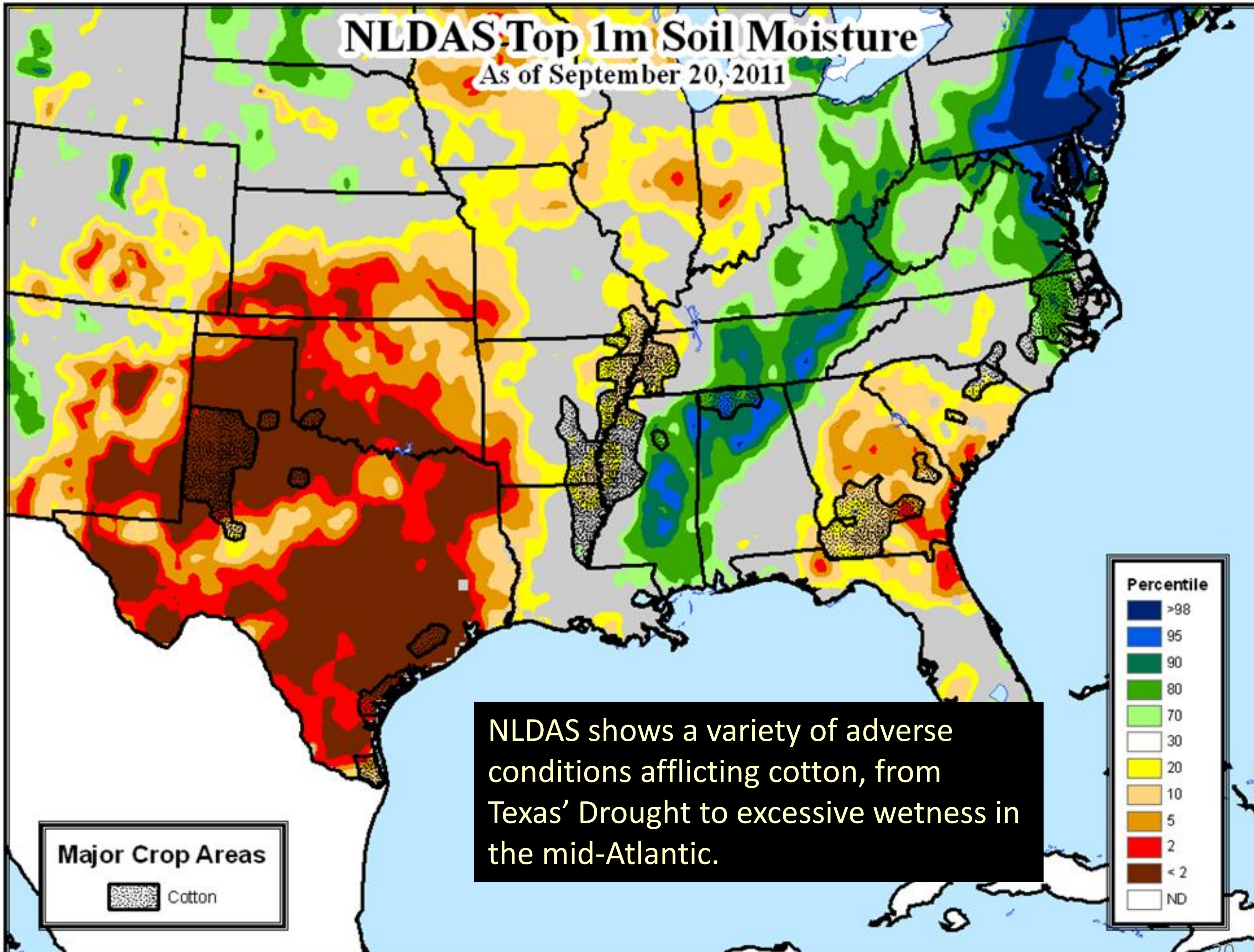
Geotiffs of NLDAS are imported directly into the US Drought Monitor (USDM) editing process via GIS.

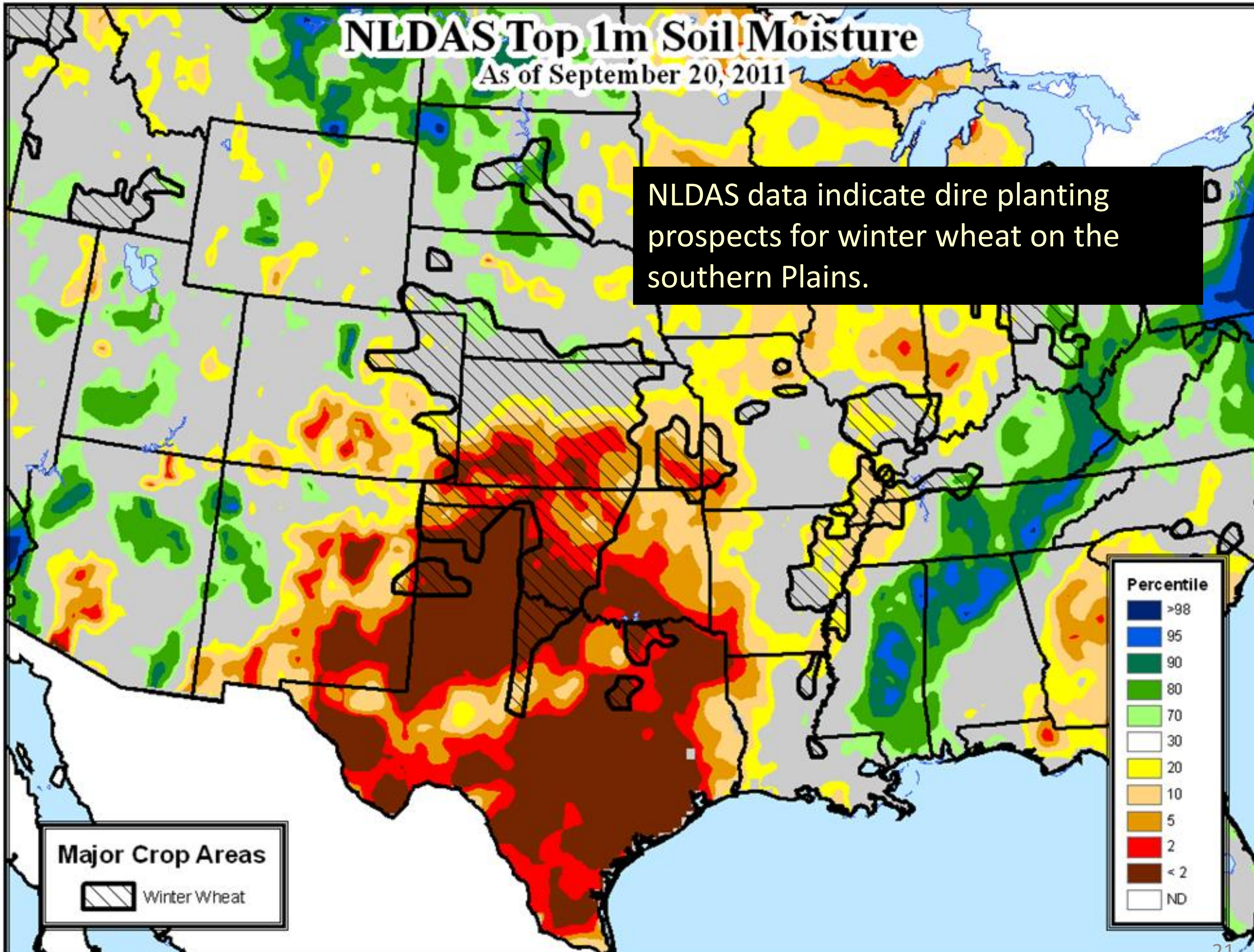



NLDAS Total Column Soil Moisture
As of September 20, 2011
NLDAS GIS data are an integral part of the USDM process, both operationally and also as part of a weekly ppt sent to the USDM Listserv.
Percentile
>98
95
90
80
70
30
20
10
5
2
< 2
ND
NLDAS website: http://www.emc.ncep.noaa.gov/mmb/nldas



NLDAS GIS data are also used in conjunction with USDA crop-area shapefiles for crop-weather assessment. Here, recent dryness depicted in the Corn Belt.

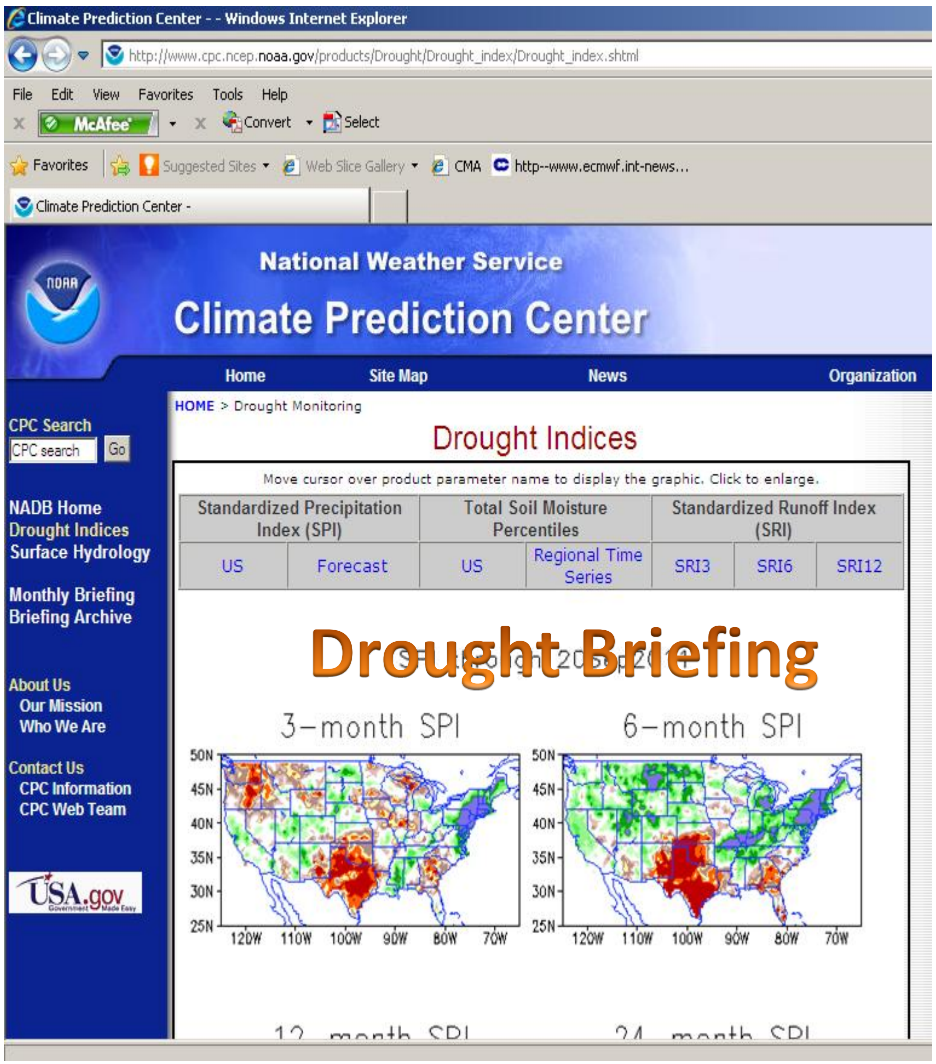

NLDAS Top 1m Soil Moisture
As of September 20, 2011
Major Crop Areas
Cotton
Percentile
>98
95
90
80
70
30
20
10
5
2
< 2
ND
NLDAS shows a variety of adverse conditions afflicting cotton, from Texas' Drought to excessive wetness in the mid-Atlantic.

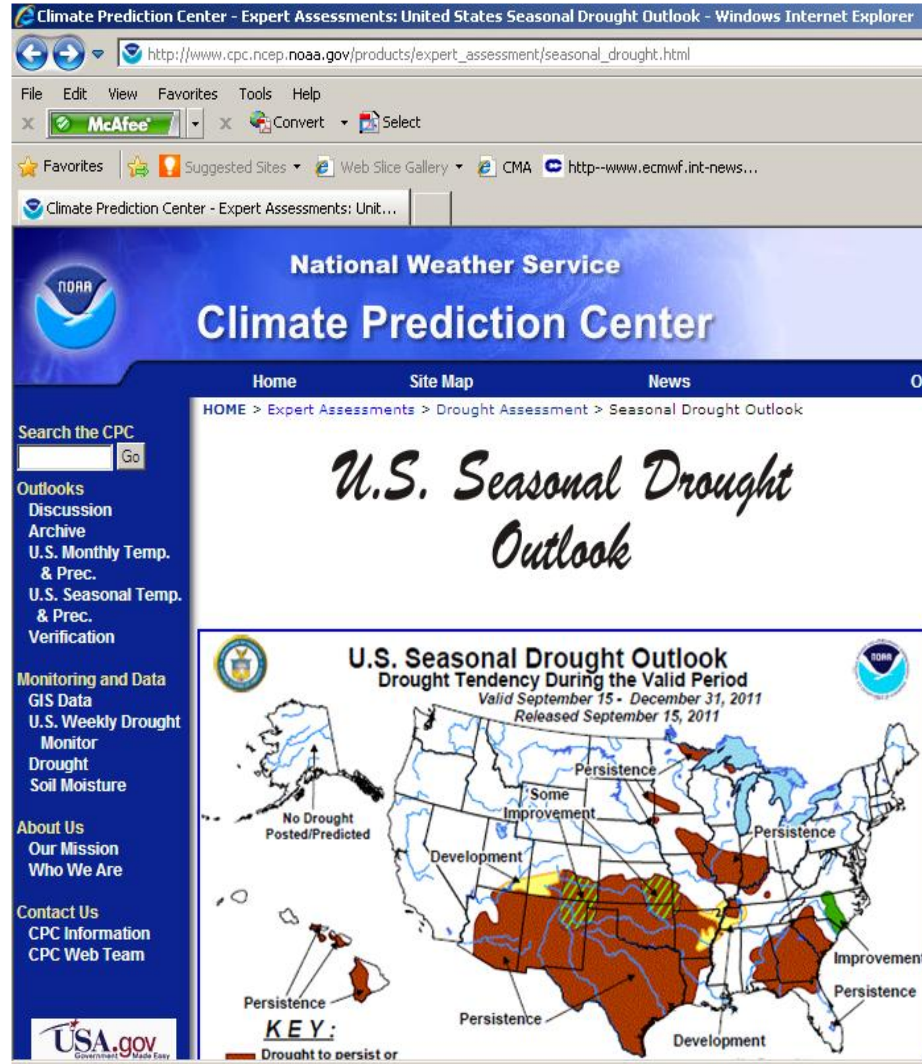


NLDAS data indicate dire planting prospects for winter wheat on the southern Plains.

NLDAS Support for NCEP/CPC

Drought Monitoring & Assessment Activity





NLDAS Past, Present and Future
Monitoring Mode

- Past:
  - Phase 1 (2000-2005) – to establish NLDAS configuration, model evaluation framework, and collaboration partners.
  - Phase 2 (2006-2010) – to make long-term (30 years) retrospective NLDAS run using the improved forcing & models, to establish a quasi-operational NLDAS system to support NIDIS activities, and to assess NLDAS products using observations.
- Present:
  - Phase 3 (2011-2014) – to maintain a quasi-operational NLDAS system, to transition all codes and scripts to NCEP central computer system, and to implement NLDAS system into NCEP operations.

NLDAS Past, Present and Future
Monitoring Mode

- Future:
  - EMC will maintain two NLDAS systems: operational version (current) & research version. Any upgrades from both forcing and models from research community will be quickly implemented in the research version with internal tests at EMC (i.e. “tempest” and/or NCEP CCS computer).
  - EMC will collaborate NASA/GSFC to install LIS for the NLDAS system to construct a real data assimilation system to assimilate observed data from both in-situ and remote sensing.
  - EMC will collaborate with NWS/OHD to extend a fine scale (~4 km “HRAP” grid) NLDAS system.

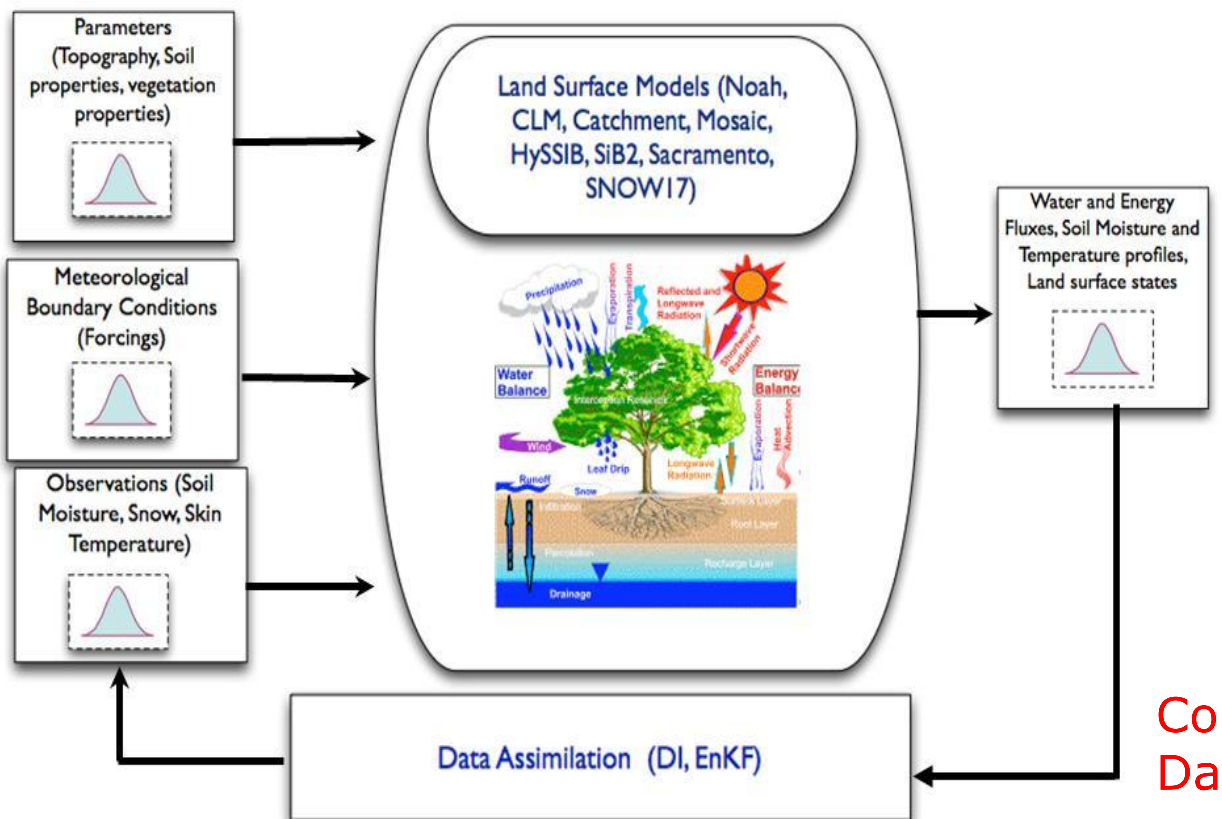
NLDAS Past, Present and Future
Monitoring Mode

- Future:
  - EMC will extend the NLDAS system from NLDAS domain to whole North America, to support North American Drought Monitor.
  - EMC will collaborate NCEP/CPC and other NLDAS partners to further extend NLDAS system from whole North America to the globe to support Global Drought Monitor being initiated by multi-countries as EMC has developed its own CFS-GLDAS system.
  - EMC will collaborate with its partners to improve land surface models (physics) and test the role of NLDAS and GLDAS initial conditions in coupled models.

NLDAS development & evaluation using the NASA Land Information System (LIS)

NLDAS LSMs to be upgraded to the latest model versions (Noah3.2/3.3, Noah-MP, GMAO's Catchment, etc.) within the Land Information System (LIS) framework, which will allow data assimilation of soil moisture and snow products to help improve drought diagnosis in NLDAS. NLDAS products and drought monitoring skill will be evaluated using numerous observations.

The Land Information System (LIS)



Using NLDAS-2 forcing in LIS with Noah3.2, Peters-Lidard et al. (2011, *Hydrological Processes*, submitted) showed an improvement of the RMSE of latent heat flux when using data assimilation of remotely-sensed soil moisture as compared to gridded FLUXNET ET data (Jung et al., 2010).

Contact: David.Mocko@nasa.gov

NLDAS Seasonal Hydrological Forecast System

- System jointly developed by Princeton University and U. Washington.

- Transitioned to EMC local system in November 2009, as an experimental seasonal forecast system.

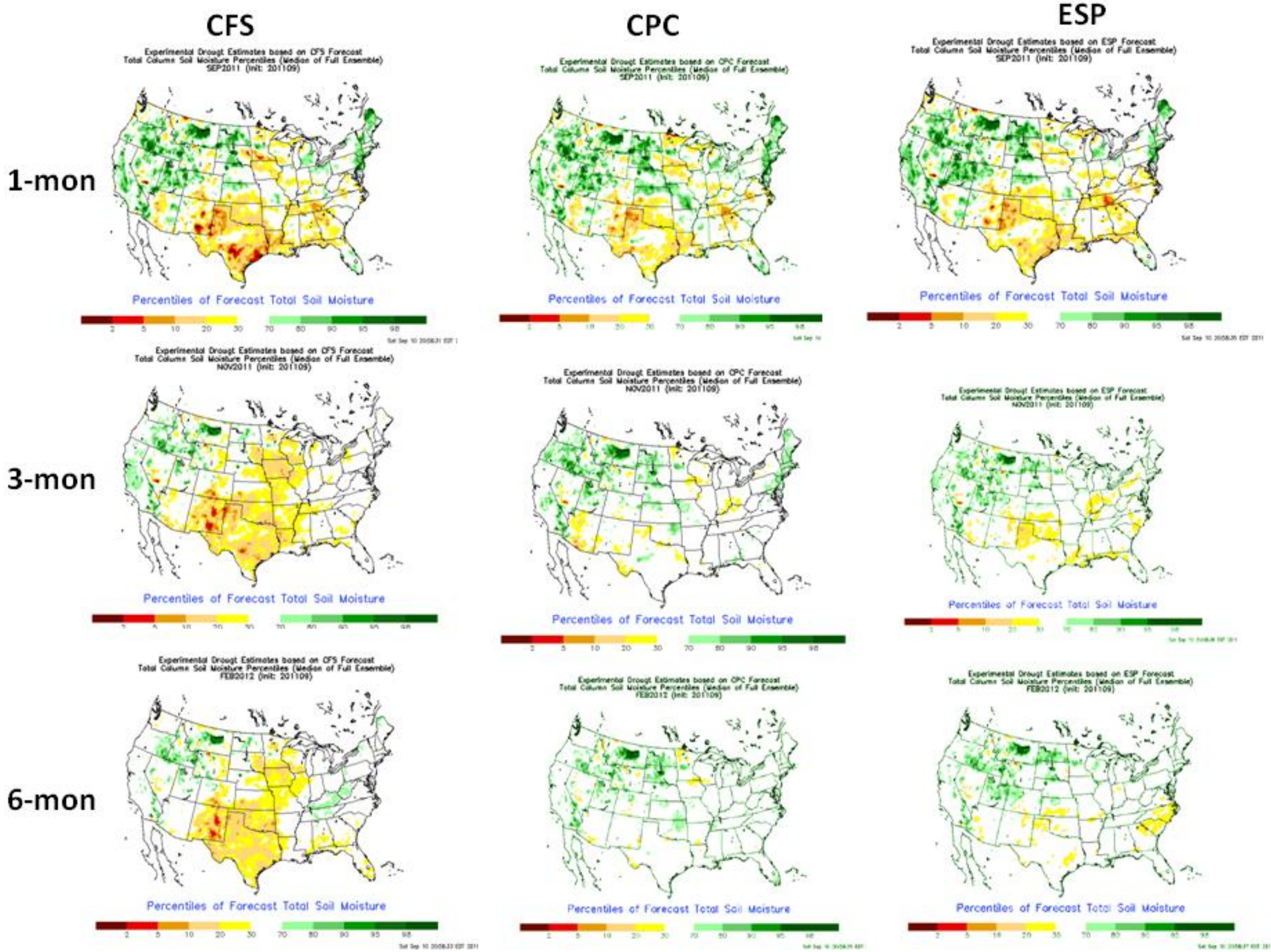
- System includes three approaches: (1) CFS forecast, (2) traditional ESP forecast, and (3) CPC forecast.

- Run at the beginning of each month and forecast products are staged on NLDAS website by the 15^{th} of each month.

- Currently uses CFSv1; will be upgraded to CFSv2.

Example based 1 September 2011 IC

1-6 month lead Total Column Soil Moisture Percentile



Example based 1 September 2011 IC

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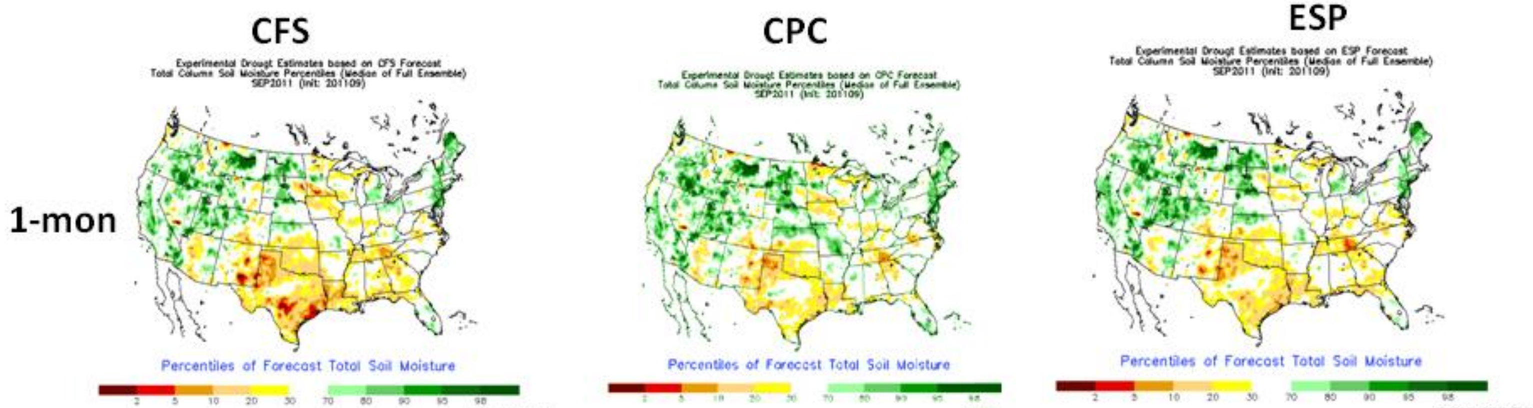
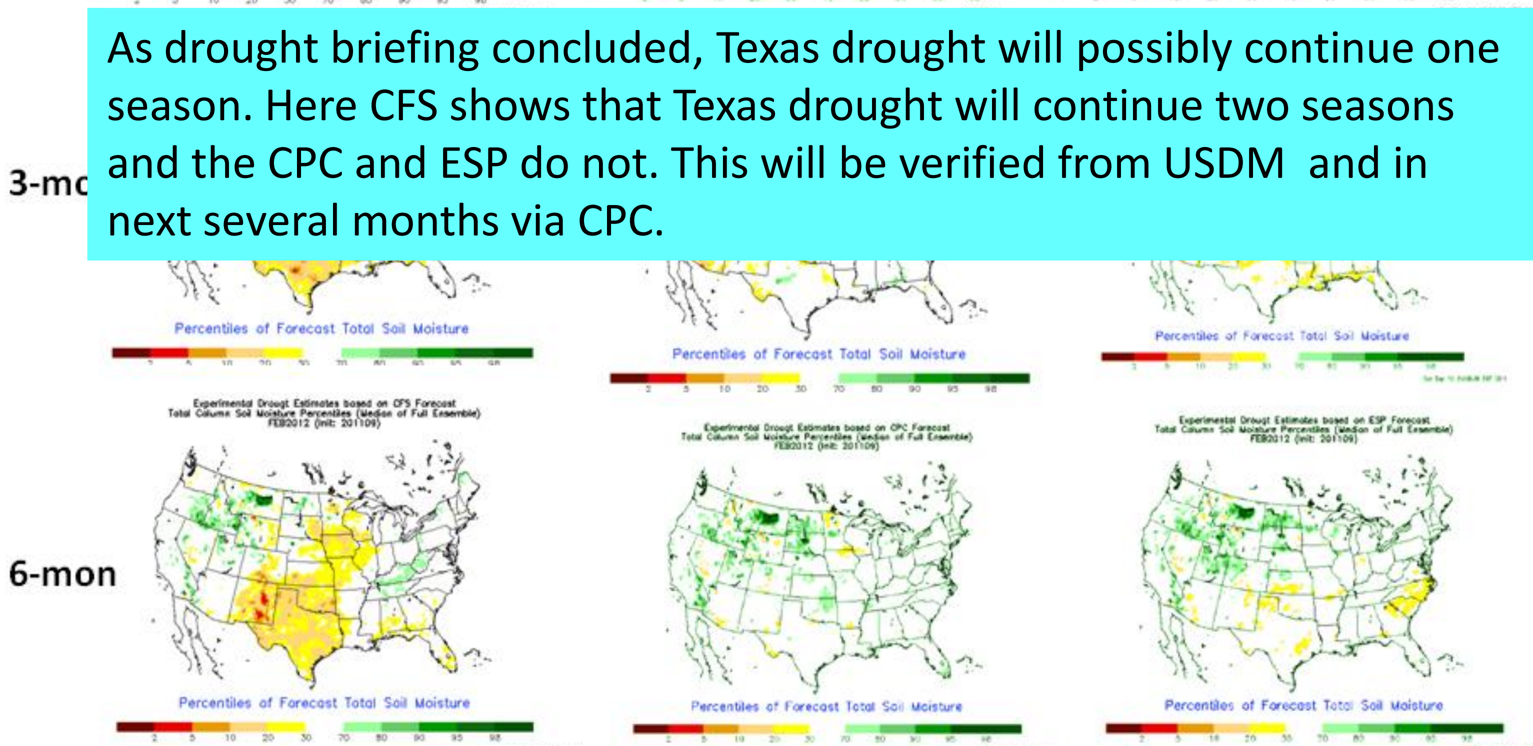


As drought briefing concluded, Texas drought will possibly continue one season. Here CFS shows that Texas drought will continue two seasons and the CPC and ESP do not. This will be verified from USDM and in next several months via CPC.



EMC and CPC's participation in NLDAS Prediction Mode

Seasonal hydrological system will be extended and assessed by a CTB project (PI: Eric Wood). As collaborators,

(1) EMC (Youlong Xia) will continue to run transitioned system (CFSv1) in quasi-operational mode to support CPC's drought briefing and seasonal drought outlook and will prepare to run its upgrade version CFSv2.
(2) EMC will collaborate with CTB PIs to move the system to CTB computer. EMC will make internal tests and evaluations of this system.
(3) EMC will collaborate with Lifeng Luo via CTB to add SAC-HT and Noah to this system.
(4) CPC (Kingtse Mo) will perform verification and assessment studies.

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HRAP-NLDAS: high resolution hydrological modeling over CONUS, HRAP grid (~4km) using operational NOAA NCEP and NOAA OHD models

The study has three main components which together provide a comprehensive suite of modeling-related improvements enabling both improved NOAA/NWS/OHD and NCEP hydrological and land surface forecasts and analyses, as well as investigations into land-atmosphere interactions:

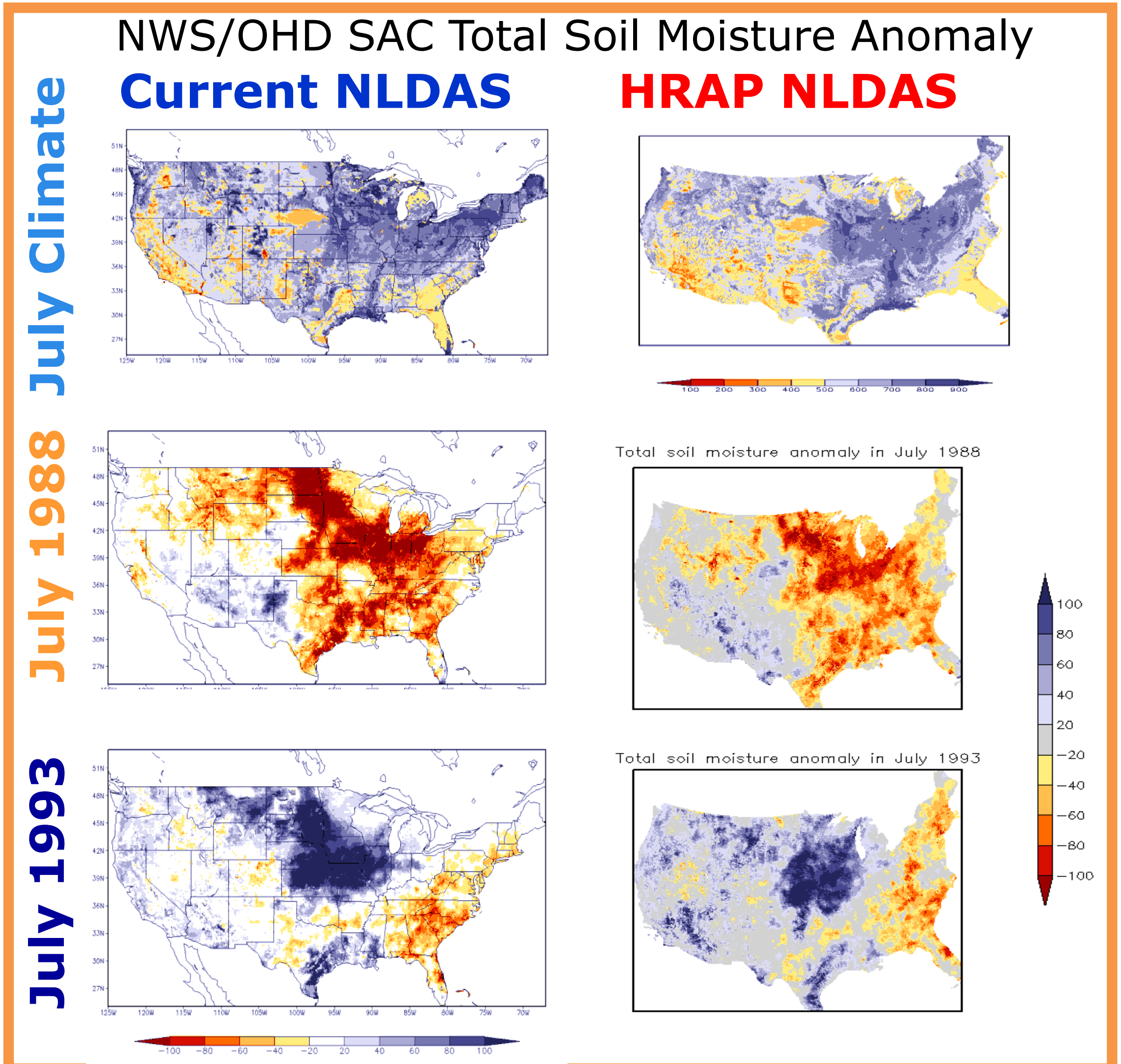
I. Model Support-Related Improvements
   - Improved downscaling of 1/8th degree NLDAS forcing to 4km HRAP grid
   - Enhanced spin-up strategies for retrospective and real-time simulations

II. Model Component Improvements
   - Improved snow assimilation modules for Noah and SAC-HT/Snow17
   - High-resolution routing capability for Noah and SAC-HT in LIS
   - Testing of NOAA ET physics in SAC-HT
   - Testing of improved sub-surface runoff modeling in SAC-HT
   - Integration of dynamic parameter calculation module into Snow17
   - Enhanced Noah bundle upgrades including snow albedo, ground water treatment.

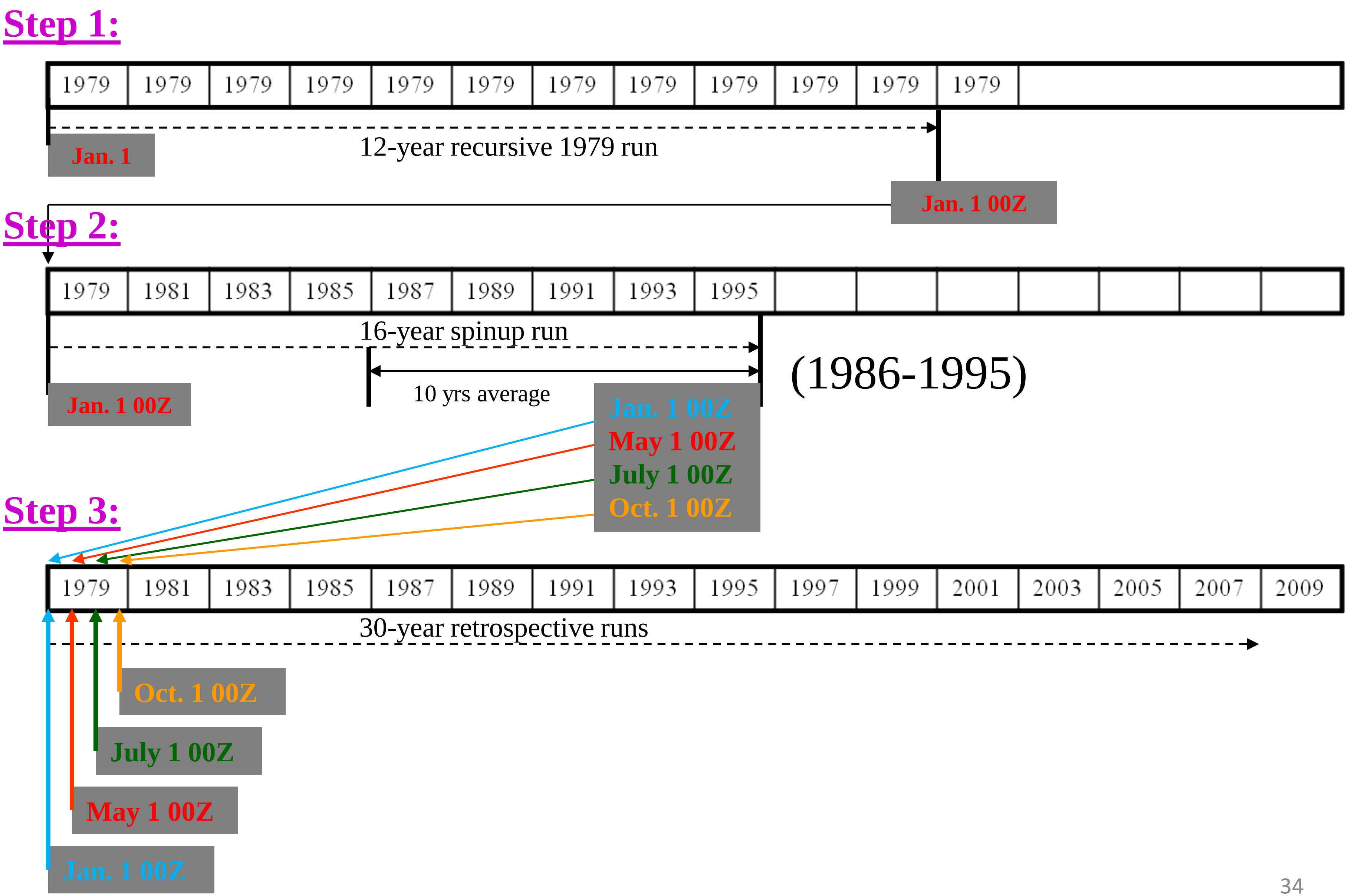
III. Model Output
   - Production of 31-year 4km retrospective SAC-HT/Noah simulations
   - Validation of model output
   - Operational application of retrospective simulations

Jiarui Dong, Brian Cosgrove (NWS/OHD) et al

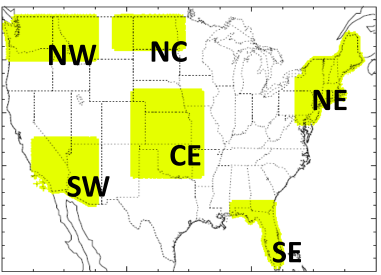
Extension from 1/8º (NLDAS) to 4 km resolution Hydrologic Rainfall Analysis Project (HRAP) grid

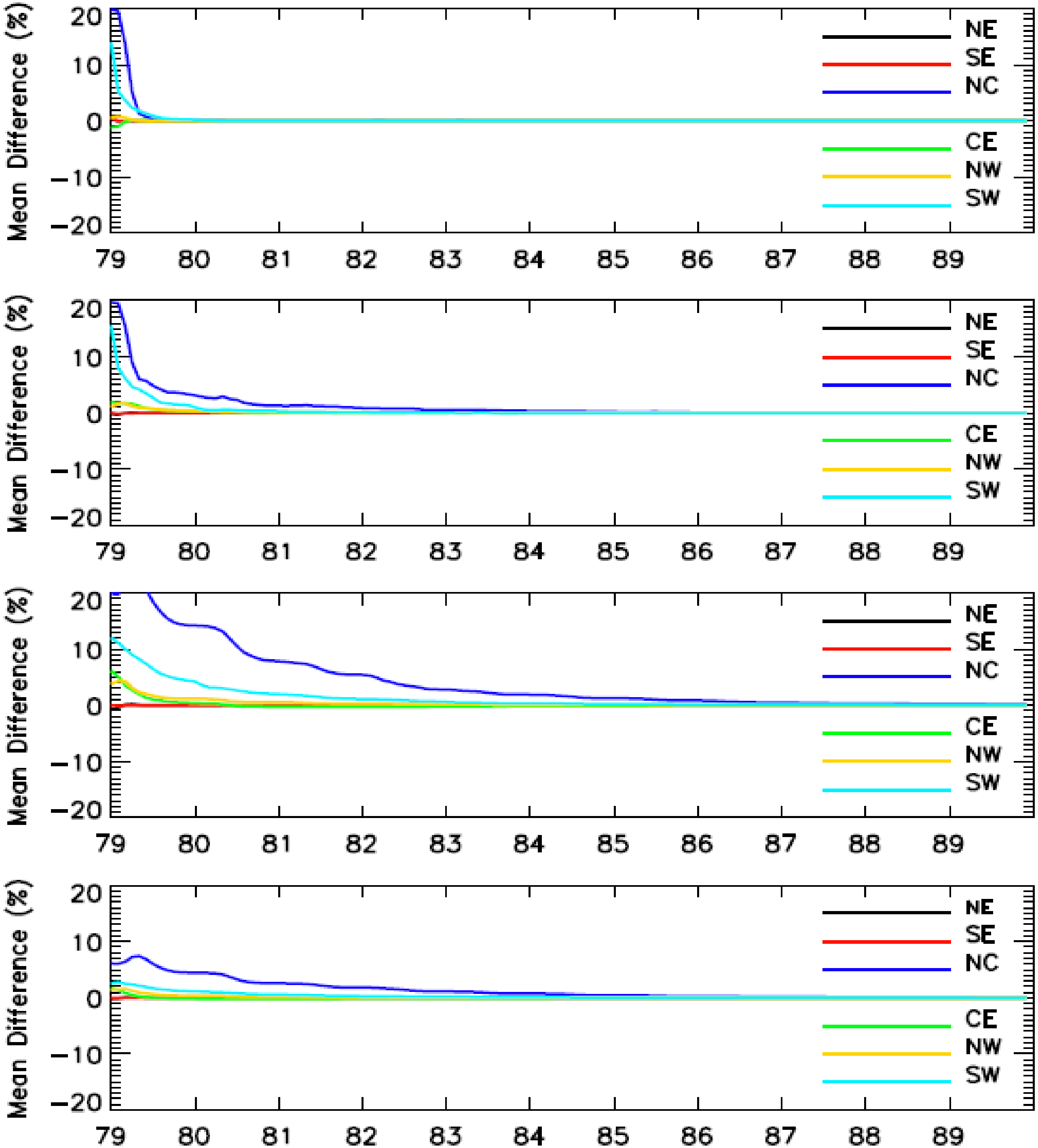


HRAP-NLDAS Spinup Strategy



Soil Moisture Spin-up





Layer 1

Layer 2

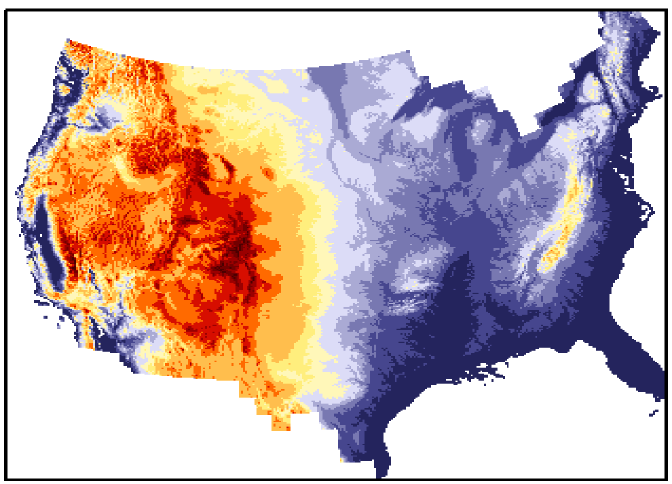
Layer 3

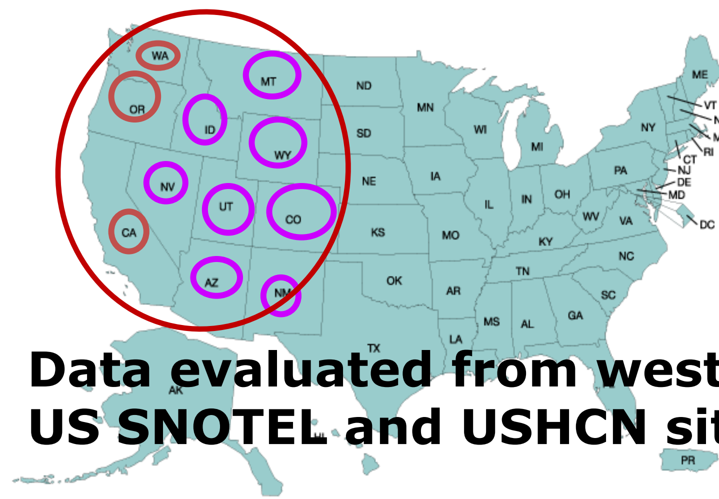
Layer 4

Run starts 2 Jan 1979

Temperature Downscaling

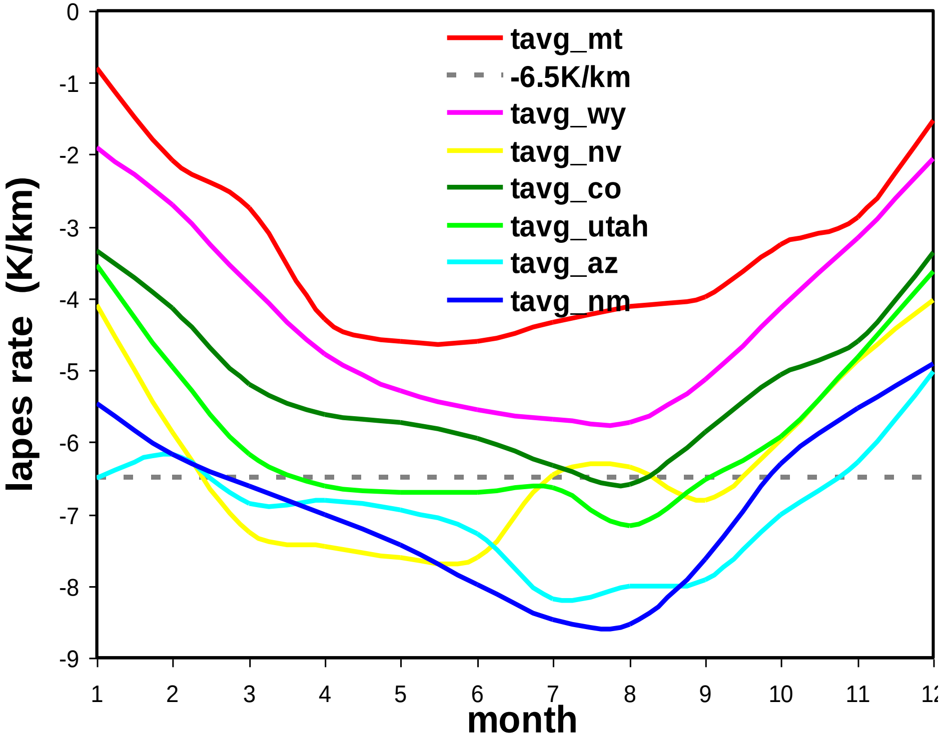
- High resolution land surface modeling requires high resolution forcing data.
- Long-term NLDAS forcing data sets hourly and 1/8th degree resolution.
- Standard downscaling uses -6.5K/km (std atmos).
- Actual near-surface lapse rate varies spatially and temporally due to the complex terrain.

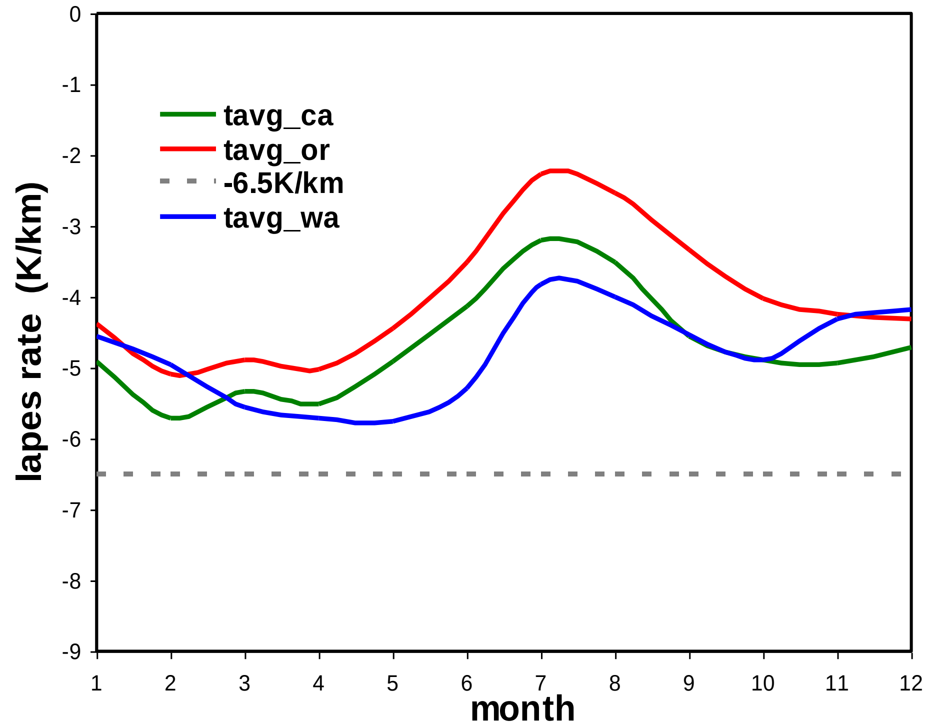




Data evaluated from western US SNOTEL and USHCN sites

Temperature Lapse Rate Adjustment





Monthly lapse rates for interior (left) & maritime (right) states

- The absolute lapse rate values are found to be larger over the southern States than over the northern States, and larger in the summer than in the winter over continental regions. Differences were found for maritime regions, where lapse rates were even smaller during the summer due to the large ocean effects.
- Temperature-based regression lapse rate can used for downscaling.

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CFS Reanalysis and Reforecast: Implementation of NASA/LIS-GLDAS

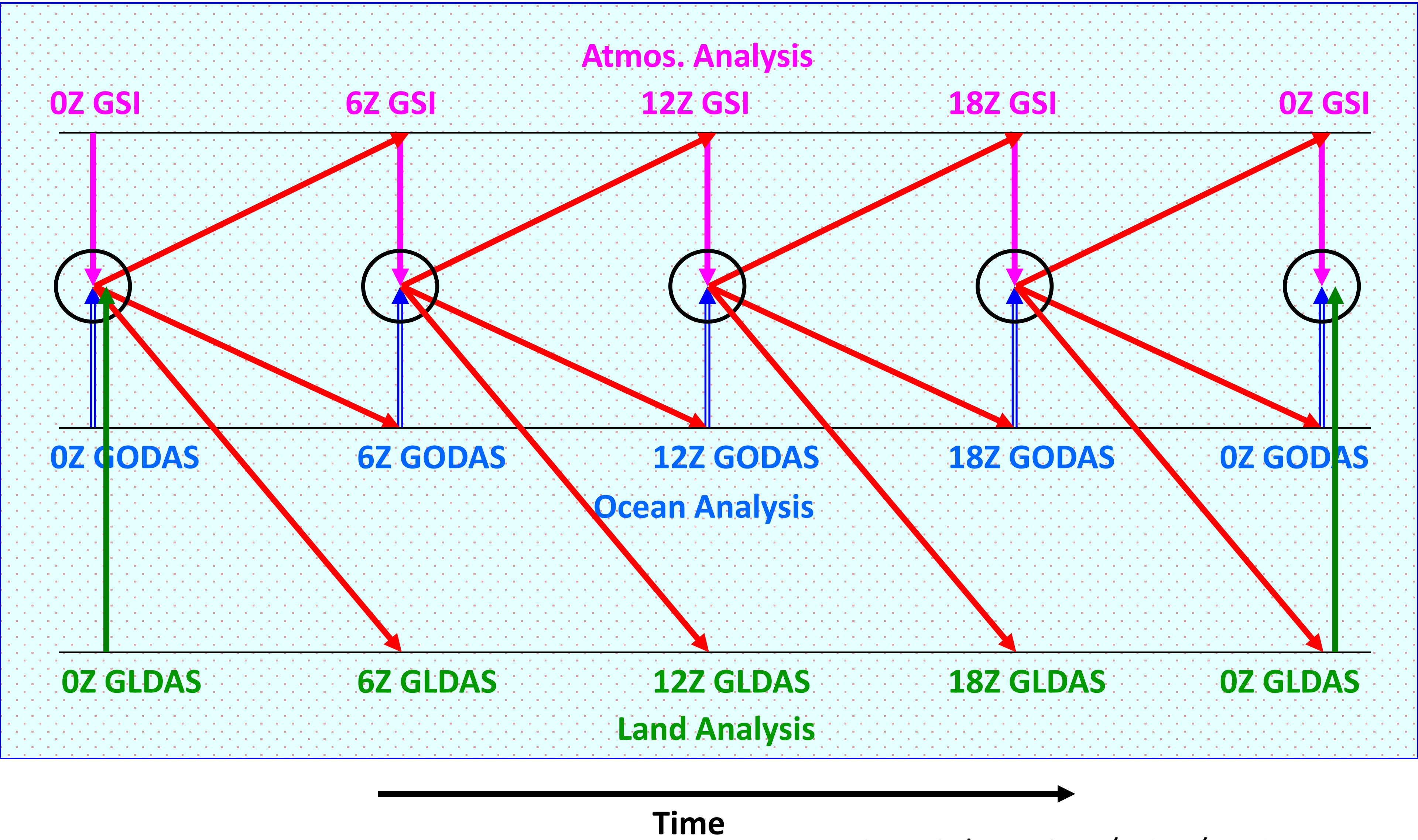
A new Global Reanalysis of the atmosphere, ocean, sea-ice and land over the 32-year period (1979-2010)

1. Analysis Systems : Operational GDAS
   - Atmospheric (GADAS/GSI)
   - Ocean-ice (GODAS)
   - Land (GLDAS/LIS)
2. Atmospheric Model : Operational GFS
   - New Noah Land Model
3. Ocean Model : New MOM4 Ocean Model
   - New Sea Ice Model

Suru Saha, NOAA/NCEP/EMC

Jesse Meng et al

CFS/CDAS execution (24-hr span):note daily GLDAS



Suru Saha, NOAA/NCEP/EMC

NASA Land Information System

Inputs

Topography,
Soils
(Static)

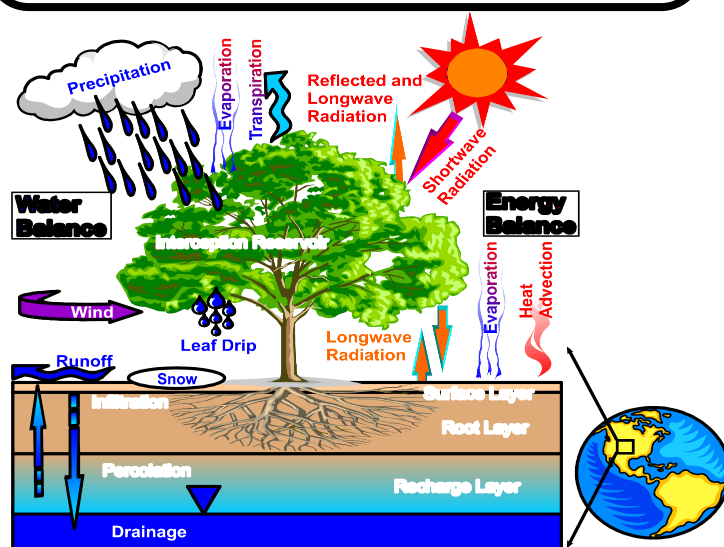
Land Cover,
Leaf Area Index
(MODIS, AMSR,
TRMM, SRTM)

Meteorology:
Modeled & Observed
(NLDAS, DMIP II,
GFS,GLDAS,TRMM
GOES, Station)

Observed States
(Snow
Soil Moisture
Temperature)

Physics

Land Surface Models
SAC-HT/SNOW17
Noah, CLM, VIC, Catchment



Data Assimilation Modules
(DI, EKF, EnKF)

Outputs

Surface
Energy
Fluxes
(Q_h,Q_{le})

Soil Moisture
Evaporation

Surface
Water
Fluxes
(e.g., Runoff)

Surface
States
(Snowpack)

Applications

Water
Supply &
Demand

Agriculture
Hydro-
Electric
Power,
Water
Quality

Improved
Short Term
&
Long Term
Predictions

Christa Peters-Lidard et al., NASA/GSFC/HSB

Comparison of Method in Assimilation of ***precipitation and snow*** in CFSv1 vs CFSv2

CFSv1:

Precip

Model precip, nudges soil moisture (1^{st} layer) during the next ***5 days*** using the difference between **CMAP** and model precip –

directly use of observed precip.

Snow

Weekly snow cover, model snowdepth is used if consistent otherwise adjusted to snow cover without affecting soil moisture –

directly use of snow cover.

CFSv2:

Precip

"Open loop" approach, uses observed precip to drive off-line Noah LSM and the resulting land states are used to update model's land states ***daily*** –

implicit use of observed precip.

Snow

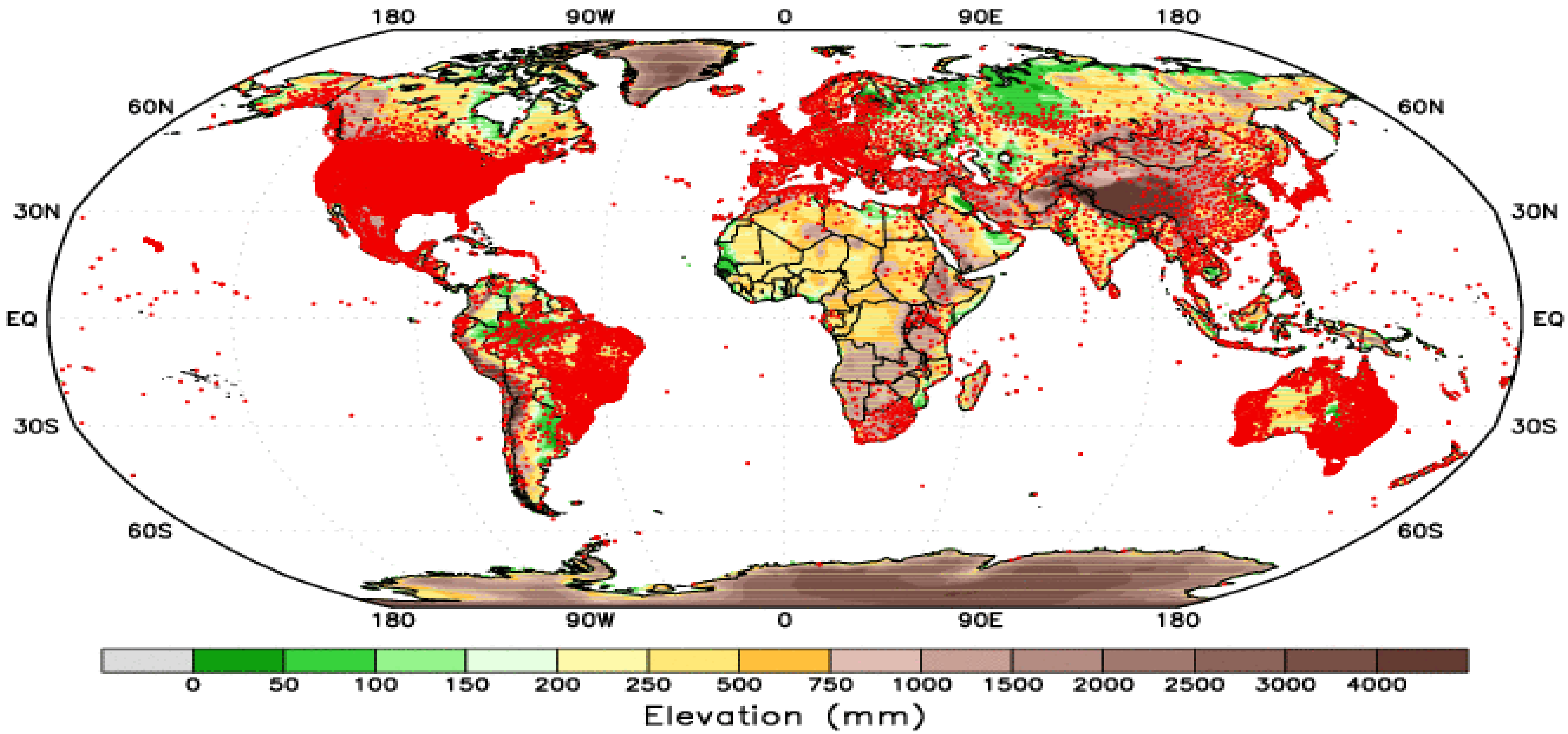
Observed snowcover and snowdepth are used to adjust (if more than twice or less than half of analysis) model's snowdepth everyday otherwise untouched –

implicit use of observed snow.

Precip forcing for CFS GLDAS

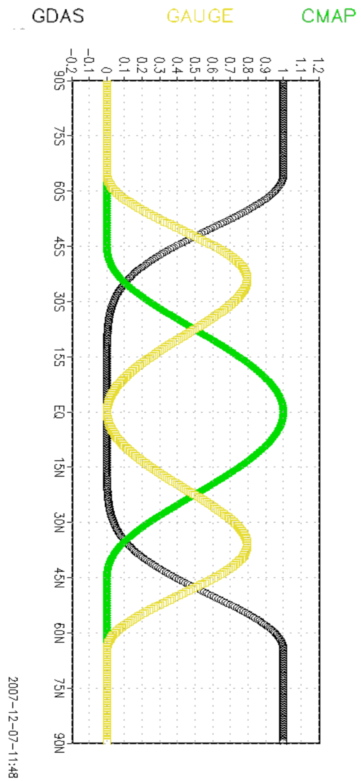
CPC Unified Daily Gauge Data

- Dense gauge networks from special CPC collections over US, Mexico, and S. America;
- GTS gauge network elsewhere
- Daily reports available from ~17,000 stations

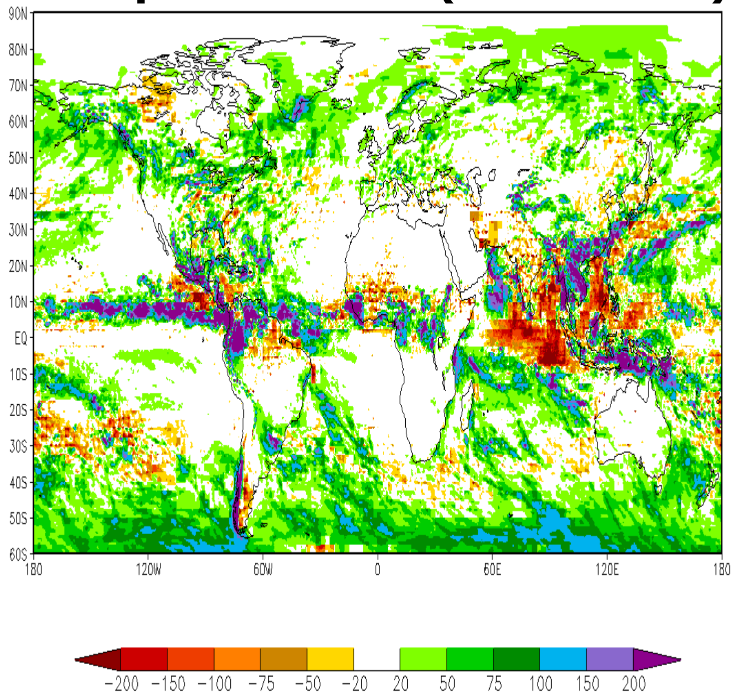


Mingyue Chen and Pingping Xie, NOAA/NCEP/CPC

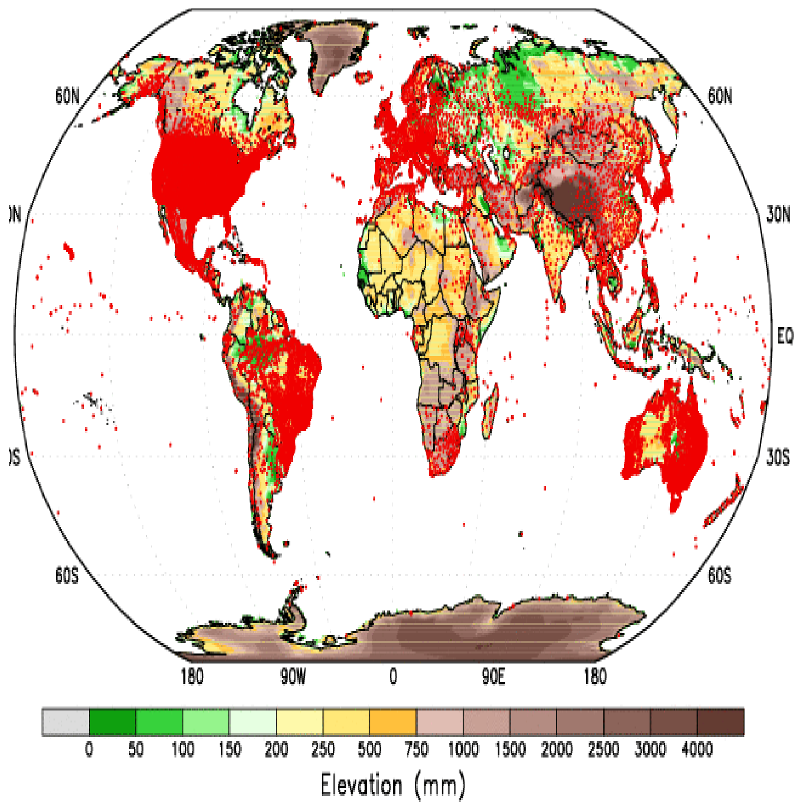
Blended precip forcing for CFS GLDAS



Precip difference (GFS-CMAP)



Global Gauge Distribution

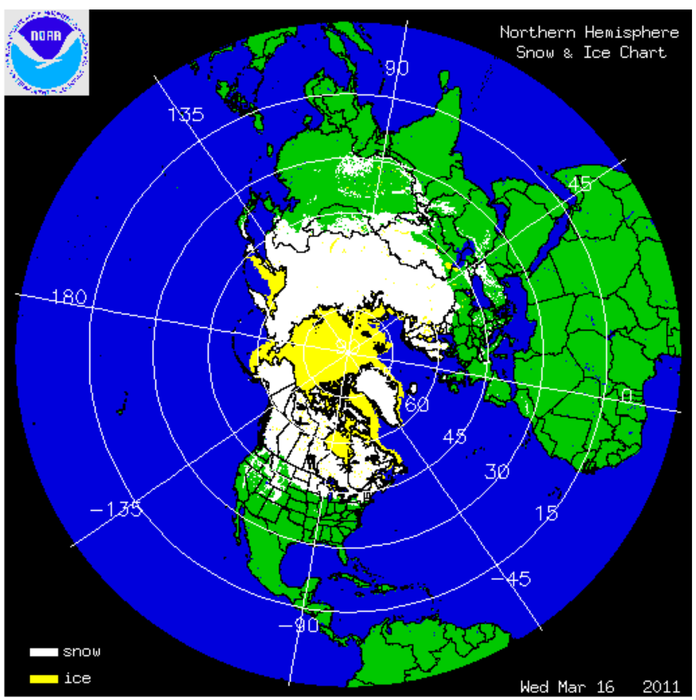


A blended precip forcing is used in CFS with the heavier weights of:
CFS/GDAS – high latitudes,
Gauge – mid latitudes,
CMAP – tropics.

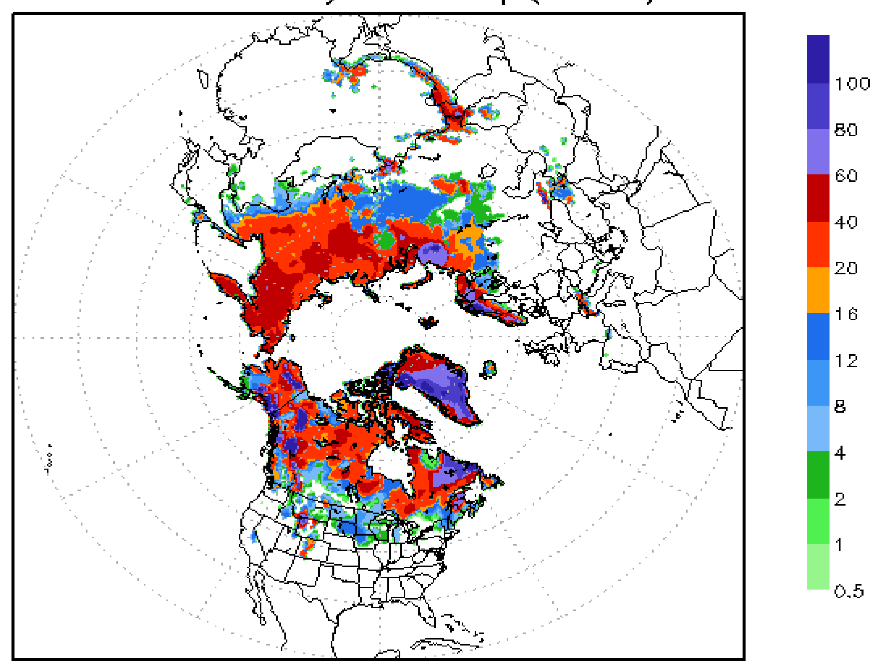
Snow analysis for CFS GLDAS

Snow cycled in CFSv2/**GLDAS** if model within 0.5x to 2.0x of observed value (IMS snow cover, and AFWA snow depth products), else adjusted to 0.5 or 2.0 of observed value.

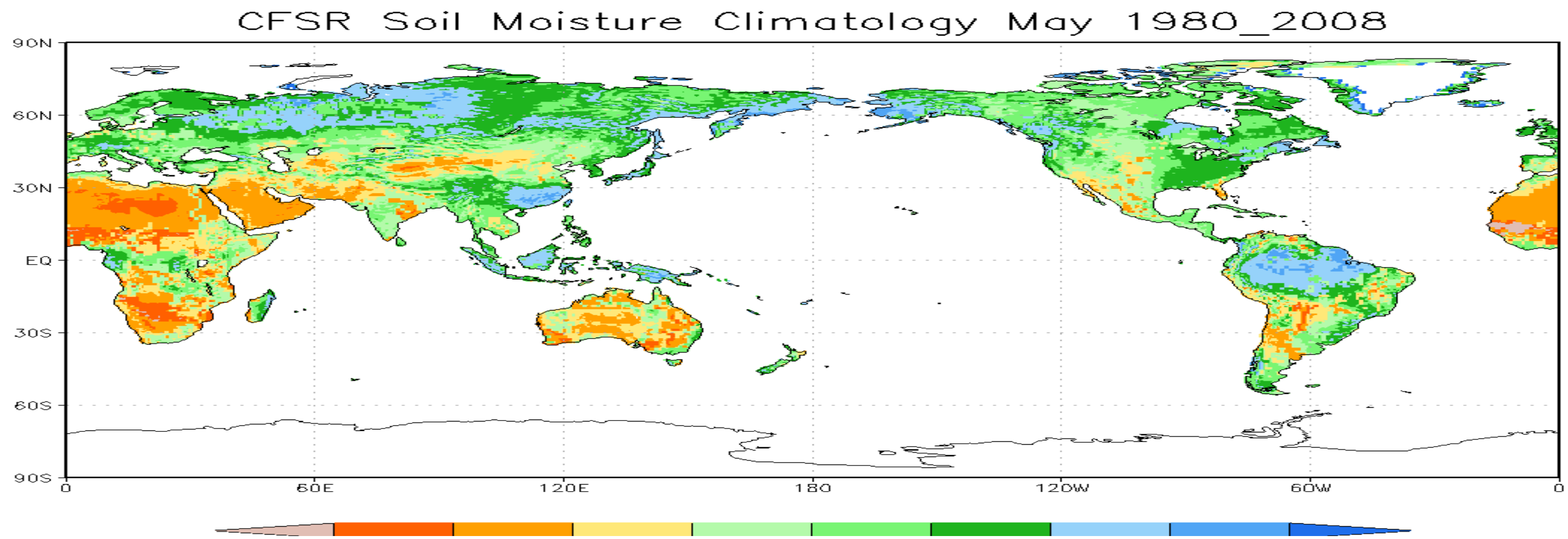
IMS Snow cover

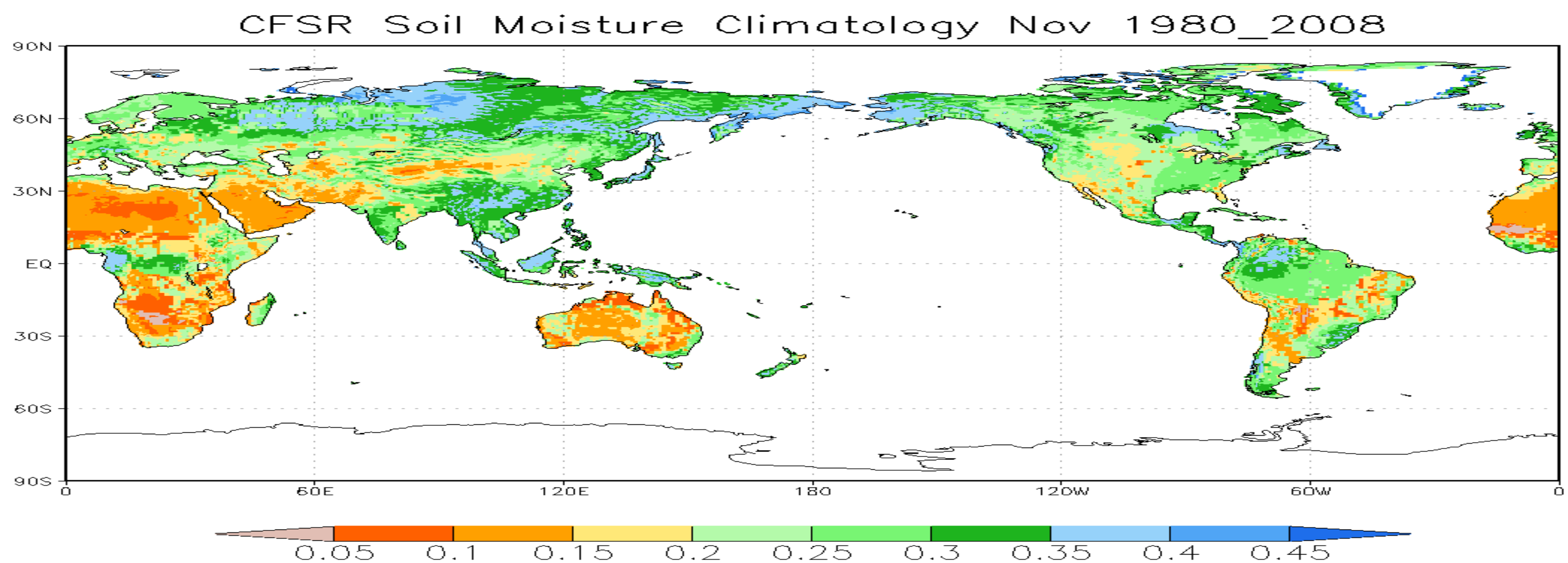


AF Snow analysis with qc(inches)

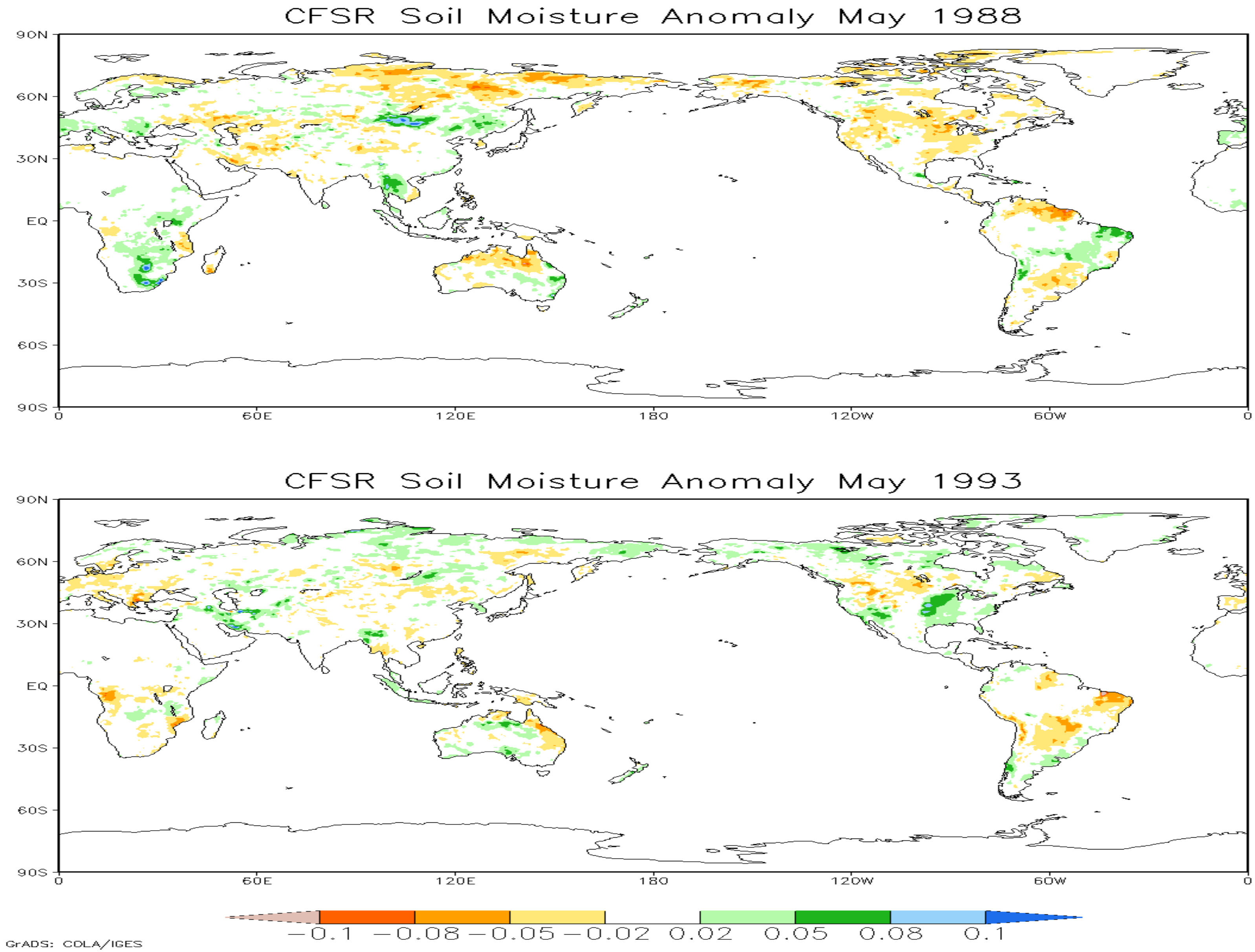


CFSR Soil Moisture Climatology



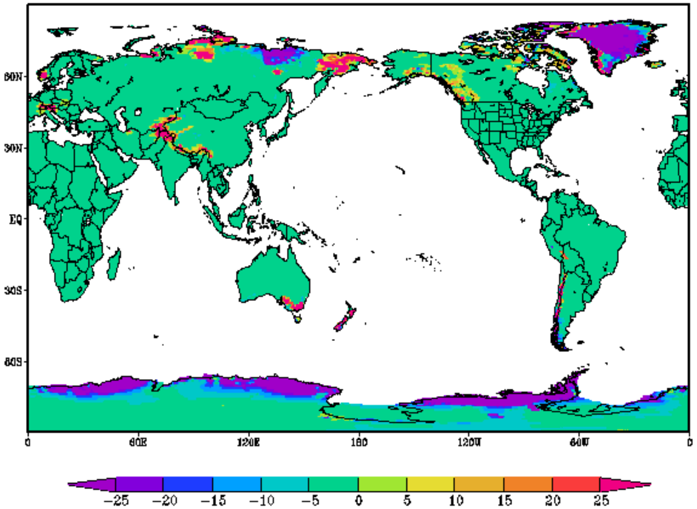


CFSR Soil Moisture Anomaly

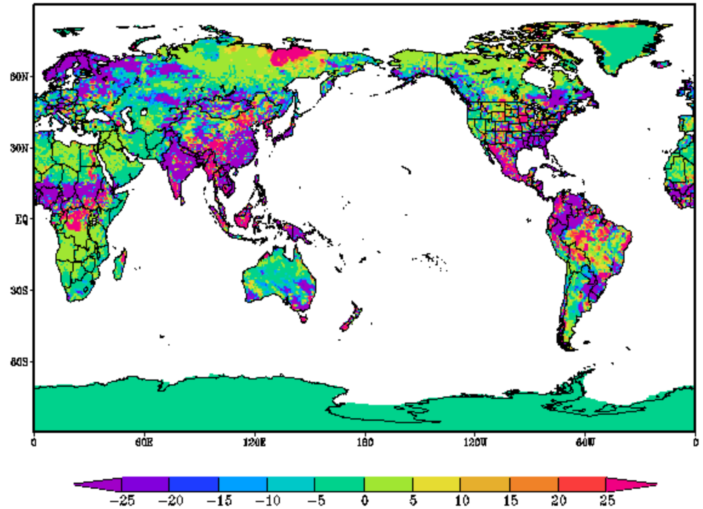


Surface Water Budget

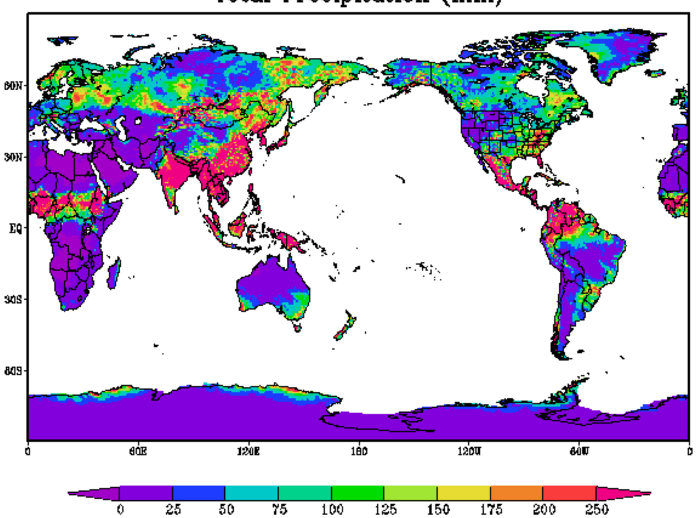
Snow Water Equivalent Updates (mm)



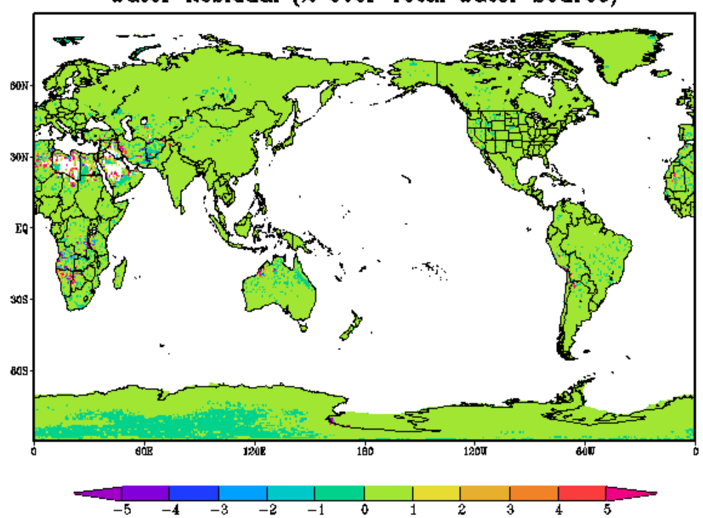
Total Soil Moisture Updates (mm)



Total Precipitation (mm)

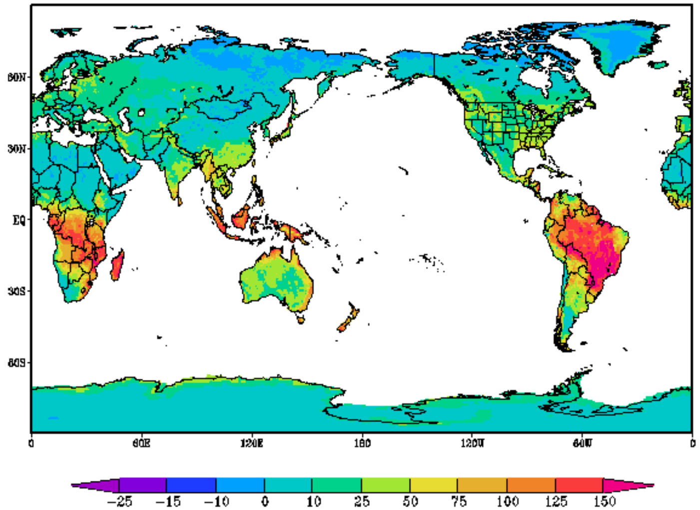


Water Residual (% over Total Water Source)

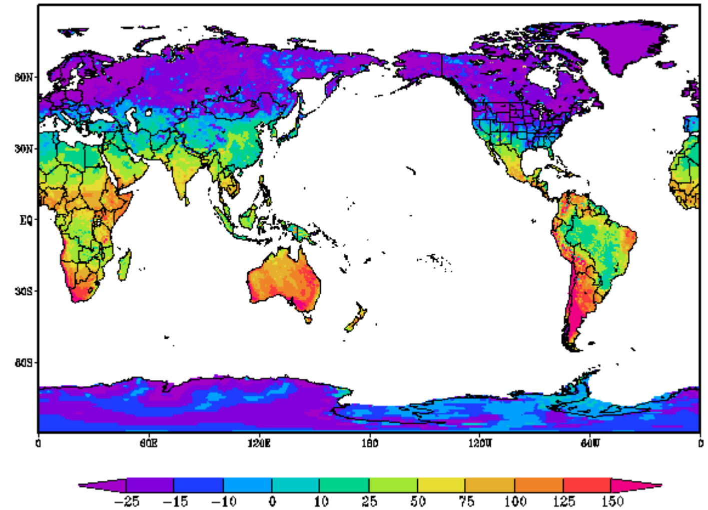


Surface Energy Budget

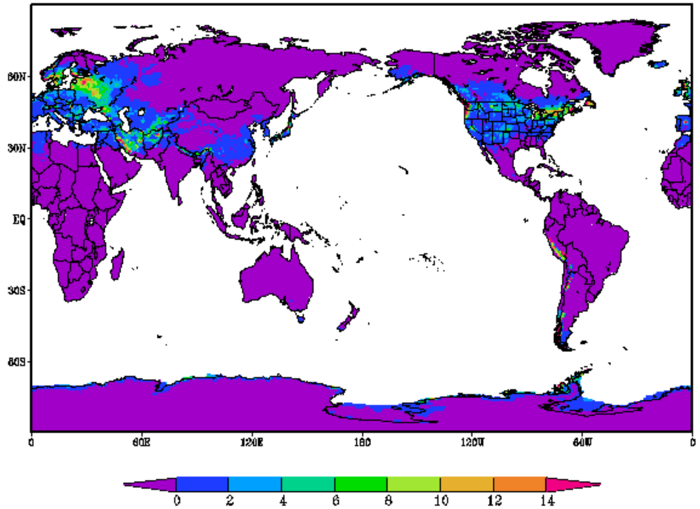
Latent Heat Flux (W/m2)



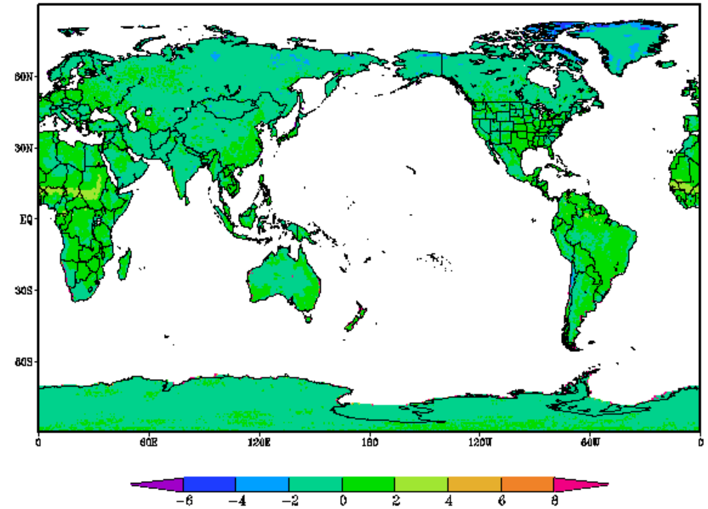
Sensible Heat Flux (W/m2)



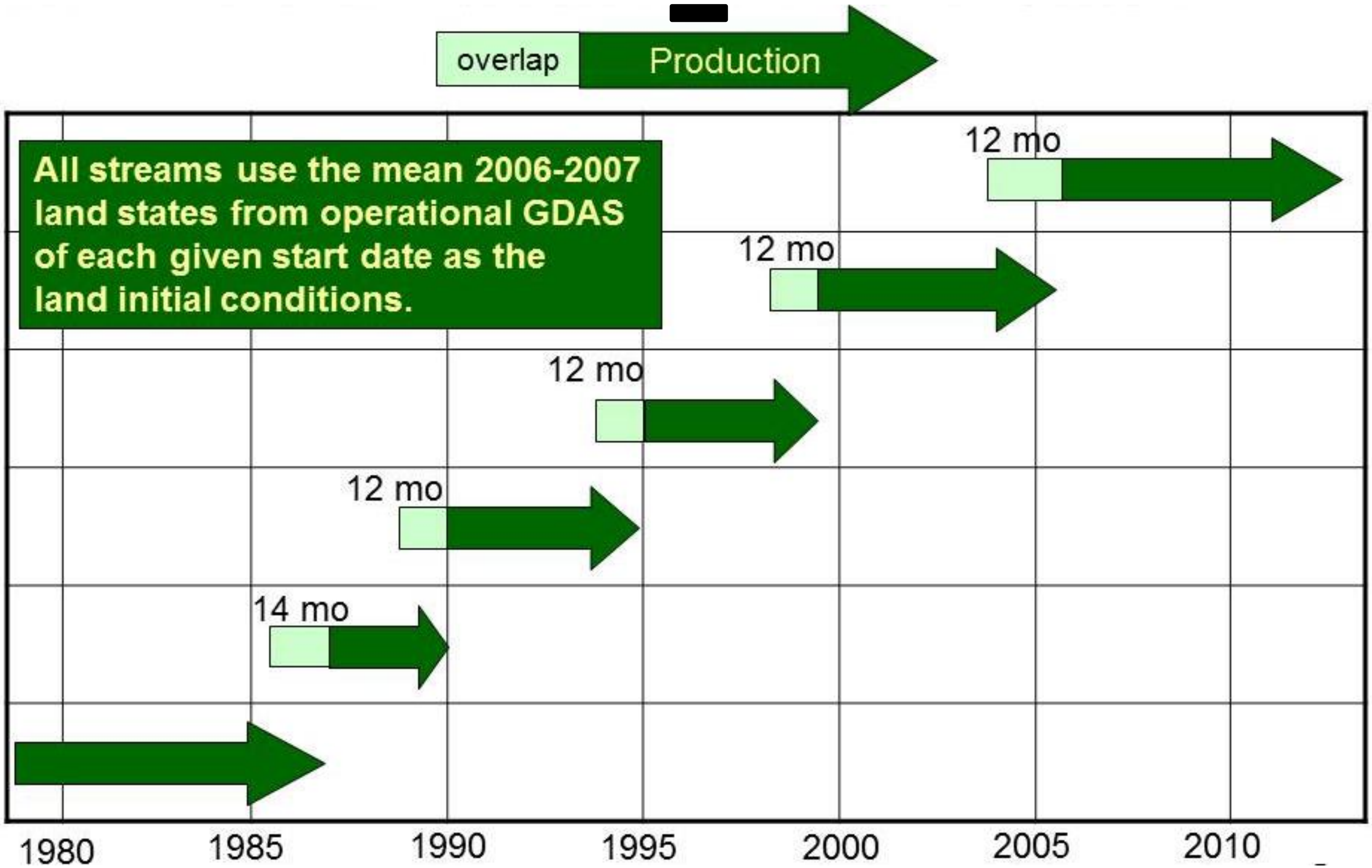
Snow Phase Change Energy (W/m2)



Energy Residual (W/m2)



CFSR Streams



NEW: Global Drought Monitor
One-stream GLDAS

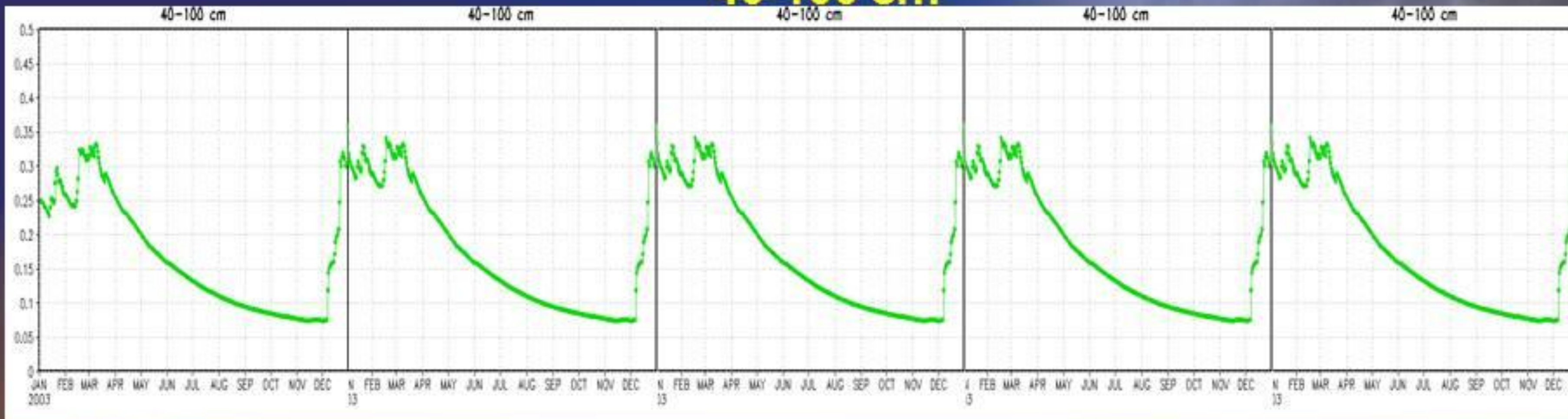
- **Motivation:** CFSR was executed in 6 streams.
- **Solution:** Proposing a One-stream GLDAS (1979-realtime).
- **Configuration:** Same as CFSR (LIS T382).
- **Forcing:** CFSR surface forcing and blended precip.
- **Initial condition:** Spin up land states for 1 January, 1979.
- **Spin up:** 1978 went from weak warm ENSO to neutral, with a similar condition, 2003 was selected for spin up forcing. Start with CFSR land states of 1 January, 2003, execute 5-year recursive spin up with 2003 forcing.

CFSR 20030101 → 2003 | 2003 | 2003 | 2003 | 2003 → GLDAS 19790101

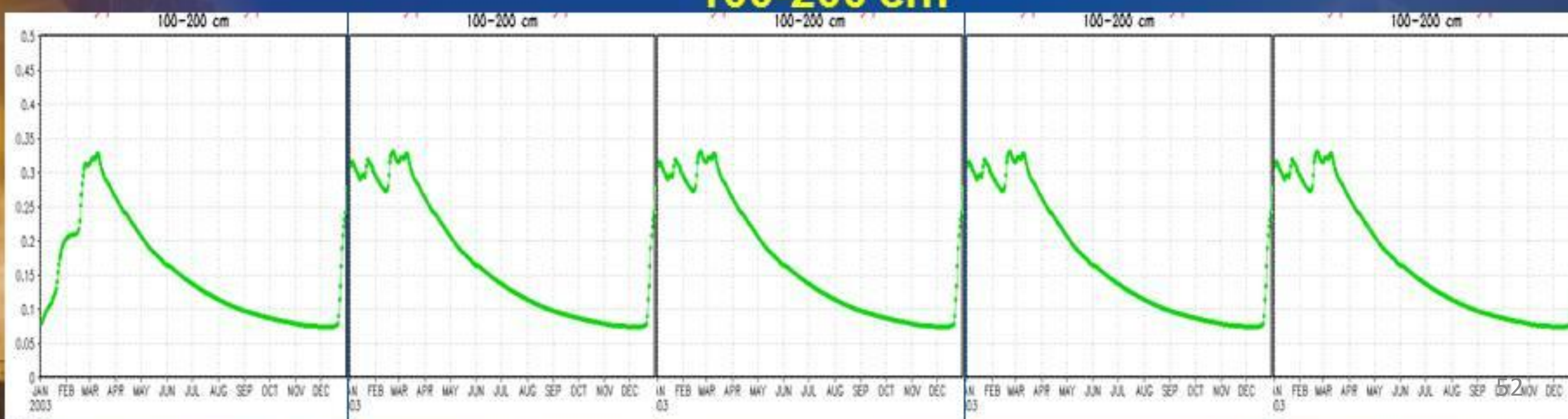
→ **GLDAS 1979-realtime**

Darwin Savanna Soil Moisture Spinup

40-100 cm

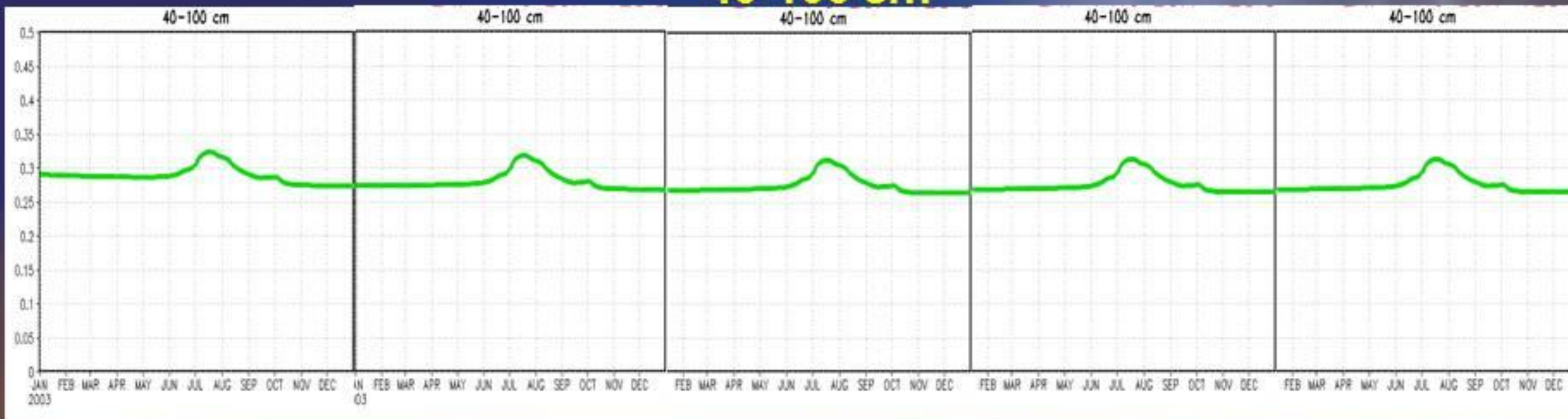


100-200 cm

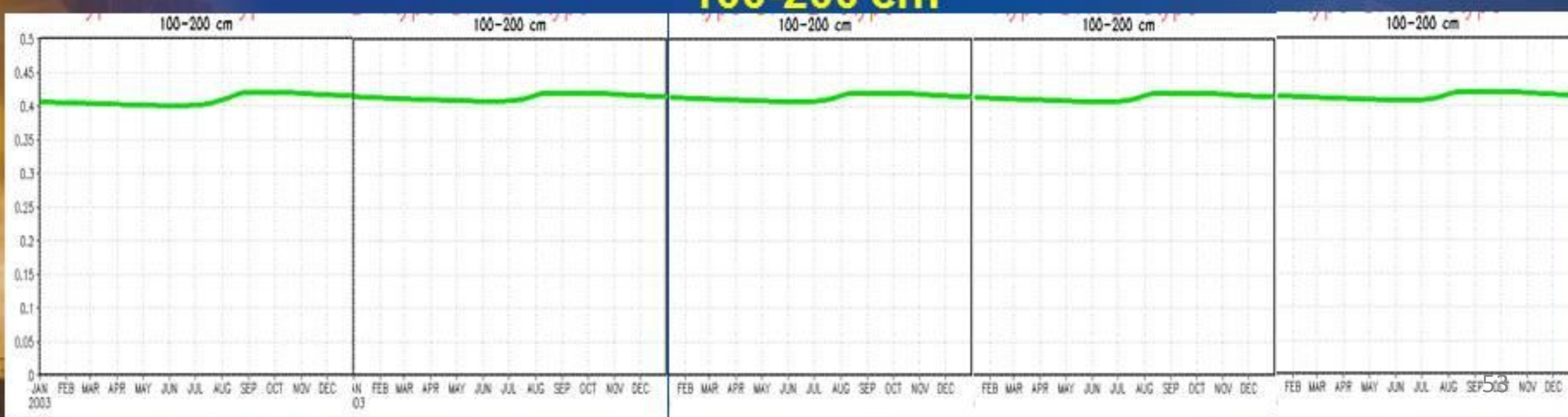


Eastern Siberia Tundra
Soil Moisture Spinup

40-100 cm

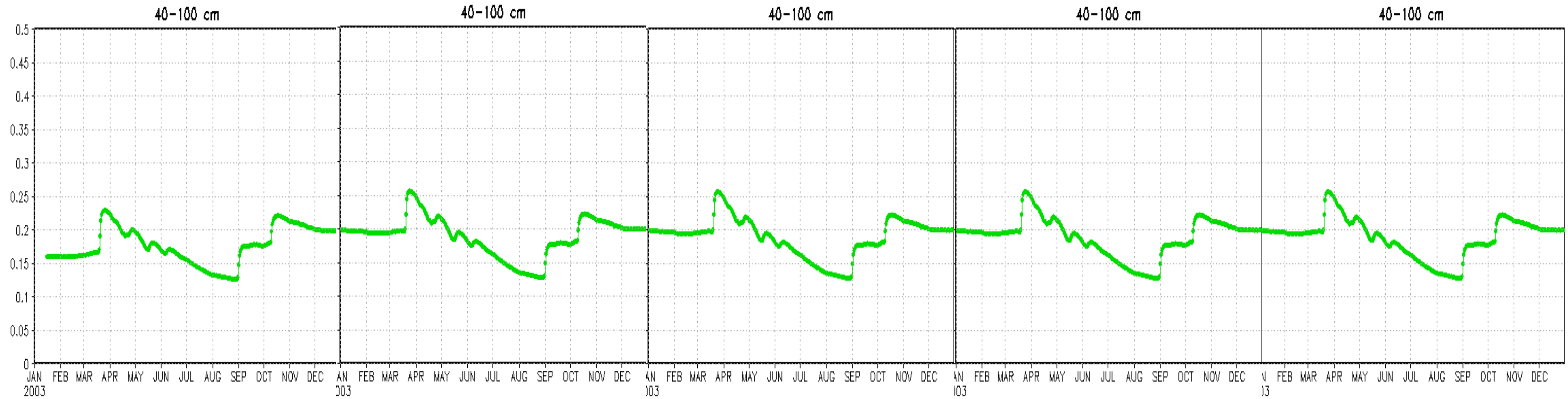


100-200 cm

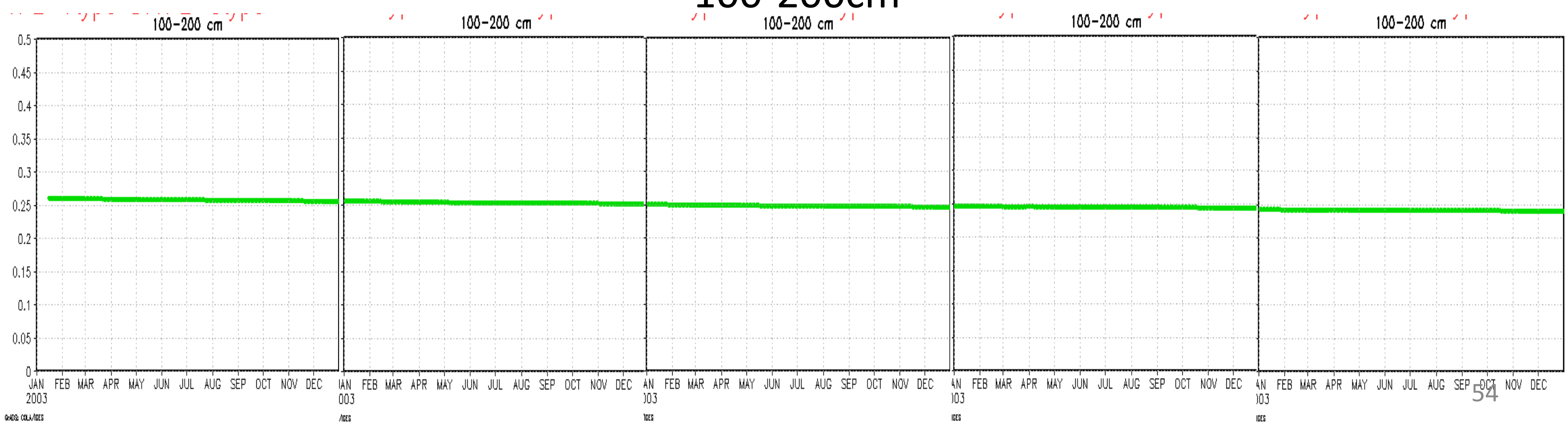


ARM Oklahoma Cropland Soil Moisture Spinup

40-100cm

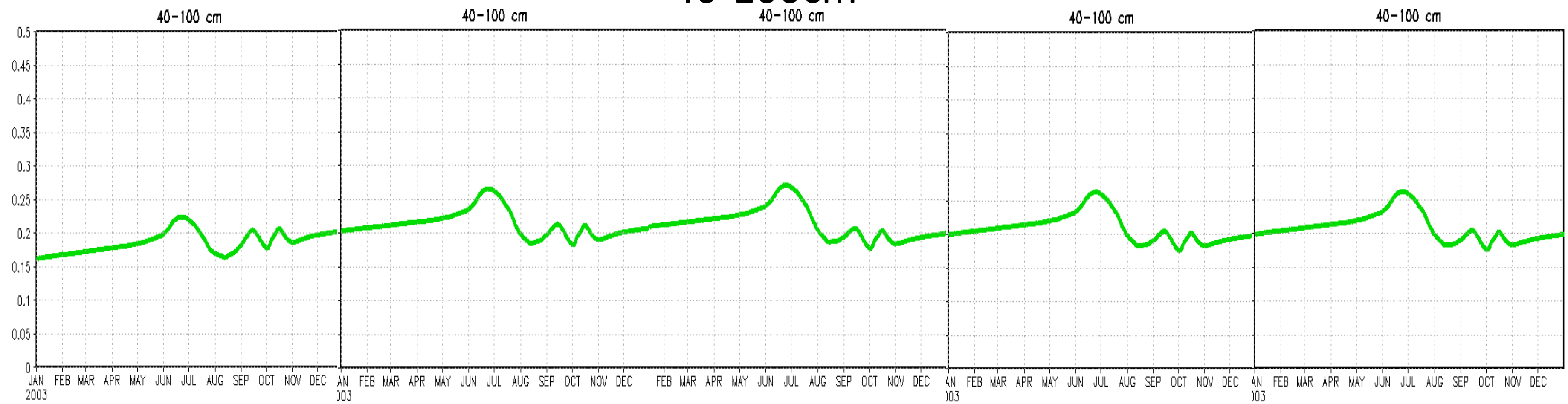


100-200cm

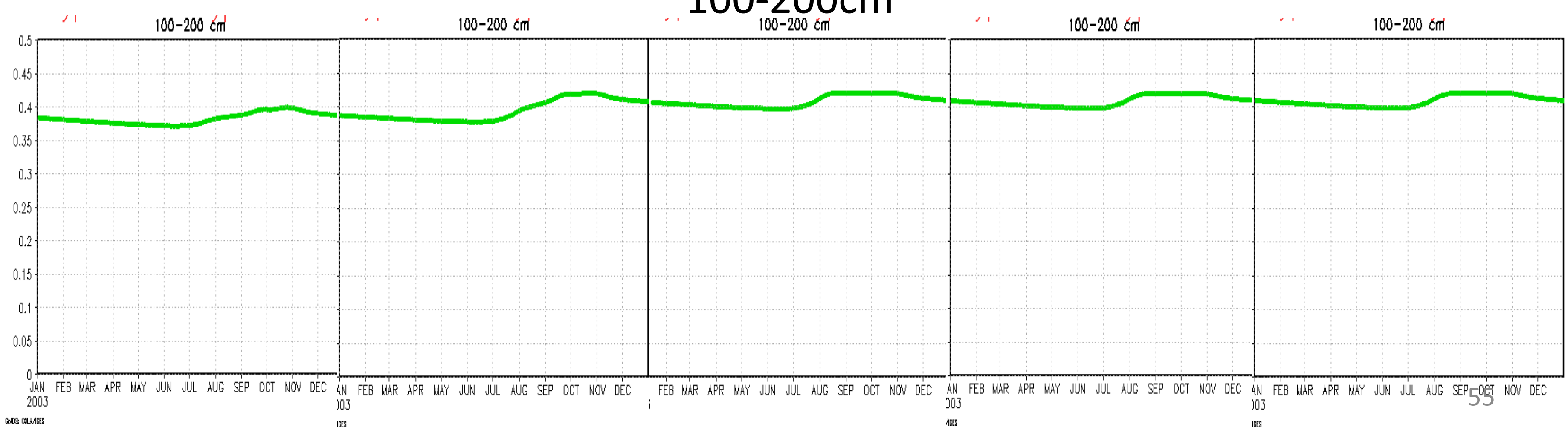


Alaska Needleleaf Soil Moisture Spinup

40-100cm



100-200cm



GLDAS SUMMARY

- CFSv2: New generation NCEP operational climate prediction/data assimilation system.
- Noah land surface model upgrades.
- **NASA/LIS infrastructure for GLDAS in CFS**
- Blended forcing to utilize observed precip to reduce the impact of forecast model bias.
- Optimal soil moisture fields consistent with prediction model physics; energy and water budgets closure.
- **Rerun 1979-present GLDAS as one stream to avoid spin-up issues.**
- **GLDAS for global drought monitoring.**

Outline

- Motivation
- Applications:
  - North American Land Data Assimilation System (NLDAS) -- "Flagship" LDAS project at NCEP
  - "HRAP"-NLDAS
  - Global LDAS (GLDAS)
- Methods/examples:
  - Surface emissivity/Tb assimilation
  - Soil moisture
  - Snow
- Summary/Future

Improvement of Satellite Data Utilization over Desert & Arid Regions

in NCEP Operational NWP Modeling and Data Assimilation Systems

- ***Problem:*** **Satellite data (IR/MW) is rarely used over desert/arid regions in GSI/CRTM (e.g. W. CONUS and N. Africa)**
  - **Substantial cold bias of land surface skin temperature (LST) in GFS.**
  - **Inaccurate emissivity calculation for MW in GSI/CRTM**
- **Improvement of land surface skin temperature (LST) in GFS**
  - **New formula of thermal roughness length (Zot) (X. Zeng et al**

$$\ln(z_{0m} / z_{0t}) = (1 - GVF)^2 \, Czil \, k \, (u_* z_{0g}/v)^{0.5}$$

$$\ln(z_{0m}) = (1 - GVF)^2 \ln(z_{0g}) + [1 - (1 - GVF)^2] \ln(z_{0m})$$

NCEP GFS OPS: $z_{0t} = z_{0m}$

- **New emissivity calculation for MW in GSI/CRTM**
  - **Empirical emissivity model over desert region (B. Yan and F. Weng).**

Tb Simulation in GSI:

IR **NOAA-17 HIRS3:** ***Ch8: 11-micron***

MW **NOAA-18 AMSU_A:** ***Ch1: 23.8 Ghz ; Ch15: 89.0 Ghz ;***

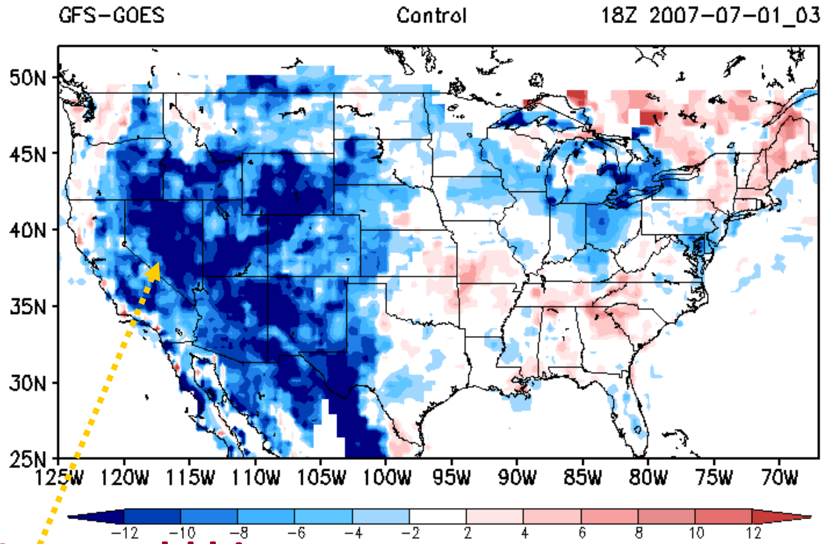
Ch4: 52.8 Ghz

Weizhong Zheng et al

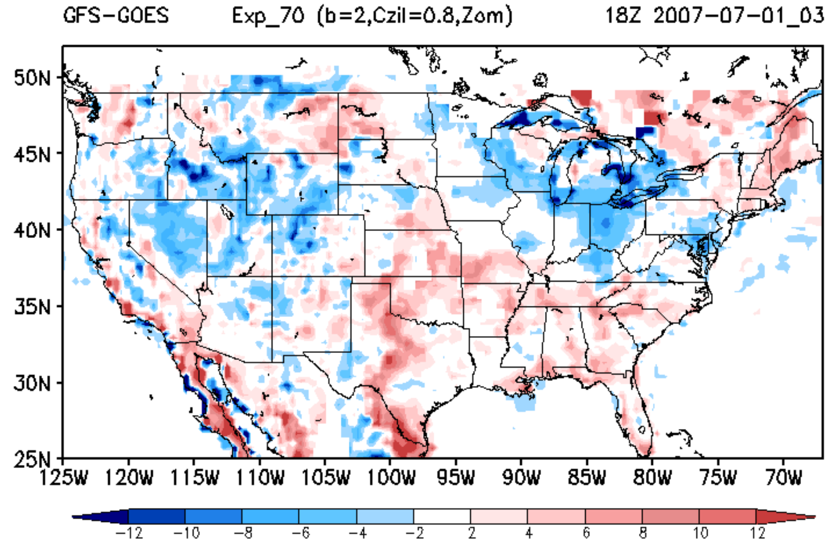
LST [K] Verification with GOES and SURFRAD

3-Day Mean: July 1-3, 2007

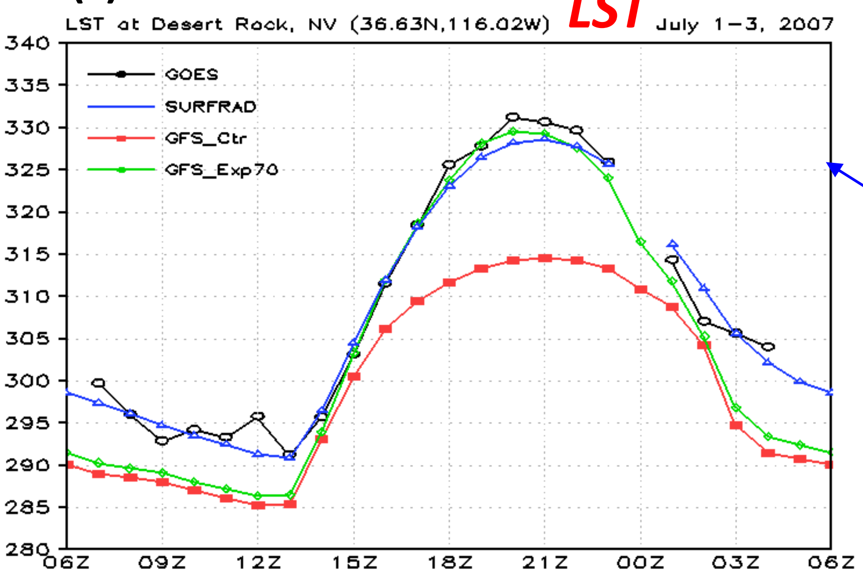
(a) GFS-GOES: CTR



(b) GFS-GOES: New Zot

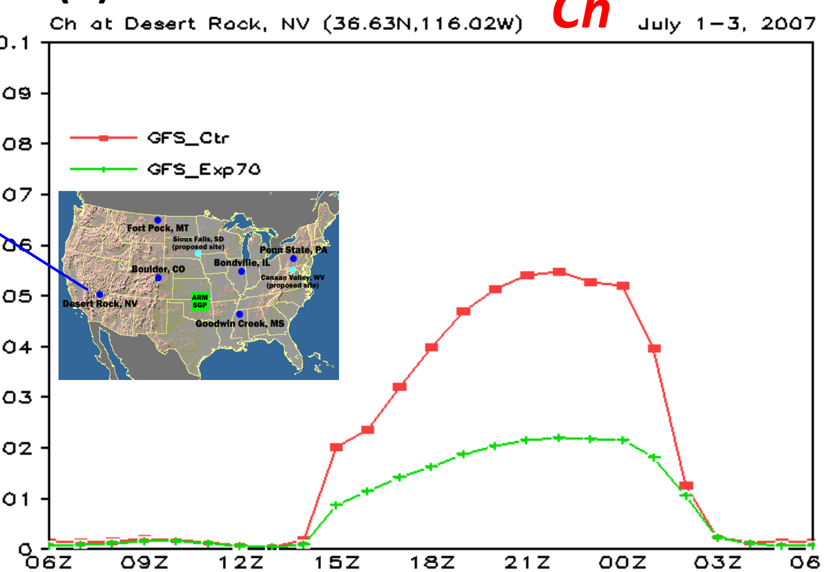


(c) LST



Improved significantly during daytime!

(d) Ch



Aerodynamic conductance: CTR vs Zot

Improvement of Satellite Data Utilization over Desert & Arid Regions *in NCEP Operational NWP Modeling and Data Assimilation Systems* ***summary***

- New formula of thermal roughness length (Zot) implemented in the NCEP GFS model to reduce a substantial cold bias of land surface skin temperature over arid and semi-arid regions during daytime in warm seasons.

- The new empirical MW emissivity model, developed by B. Yan and F. Weng at NESDIS, corrected unreasonable MW surface emissivity calculation over desert regions in CRTM.

- **With new Zot change and new emissivity MW model together, obvious reduction of large bias in calculated brightness temperatures was found for infrared and microwave satellite sensors for surface channels, so many more satellite measurements can be utilized in GSI data assimilation system.**

Microwave Land Emissivity Upgrades, Calculations in CRTM

Experiments:

GSI/CRTM off-line run: July 2010

<u>Control run :</u> Operational microwave (MW) land emissivity model;

<u>Sensitivity test 1:</u> Land surface types (soil & vegetation types);

<u>Sensitivity test 2:</u> (test 1) + Upwelling radiance from the ground.

Weizhong Zheng et al

Radiative transfer process for microwave scatting and emission material on the land surface.

The radiative transfer equation is

$$\mu\frac{dI(\tau,\mu)}{d\tau} = I(\tau,\mu) - \frac{\omega(\tau)}{2}\int_{-1}^{1} \boldsymbol{P_s}(\tau,\mu,\mu')d\mu' - [1-\omega(\tau)]B(T)$$

I: radiance,
Ω(τ): single-scattering albedo,
Ps(τ,μ,μ'): phase function,
B(T): Planck function,
T: thermal temperature,
τ: optical thickness,
μ: cosine of incident zenith angle,
μ' : cosine of scattering zenith angle.

Total upwelling radiance from the surface:

$$I_t(\tau_0,\mu) = \frac{B(T_s)(1-\beta)[1+\gamma e^{-2\kappa(\tau_1-\tau_0)}]}{(1-\beta R_{21})-(\beta-R_{21})\gamma\, e^{-2\kappa(\tau_1-\tau_0)}} + \frac{[I_0(1-R_{12})][\beta-\gamma e^{-2\kappa(\tau_1-\tau_0)}]}{(1-\beta R_{21})-(\beta-R_{21})\gamma\, e^{-2\kappa(\tau_1-\tau_0)}} + \frac{(1-R_{23})[B(T_g)-B(T_s)]\gamma_m e^{-\kappa(\tau_1-\tau_0)}}{(1-\beta R_{21})-(\beta-R_{21})\gamma\, e^{-2\kappa(\tau_1-\tau_0)}}$$

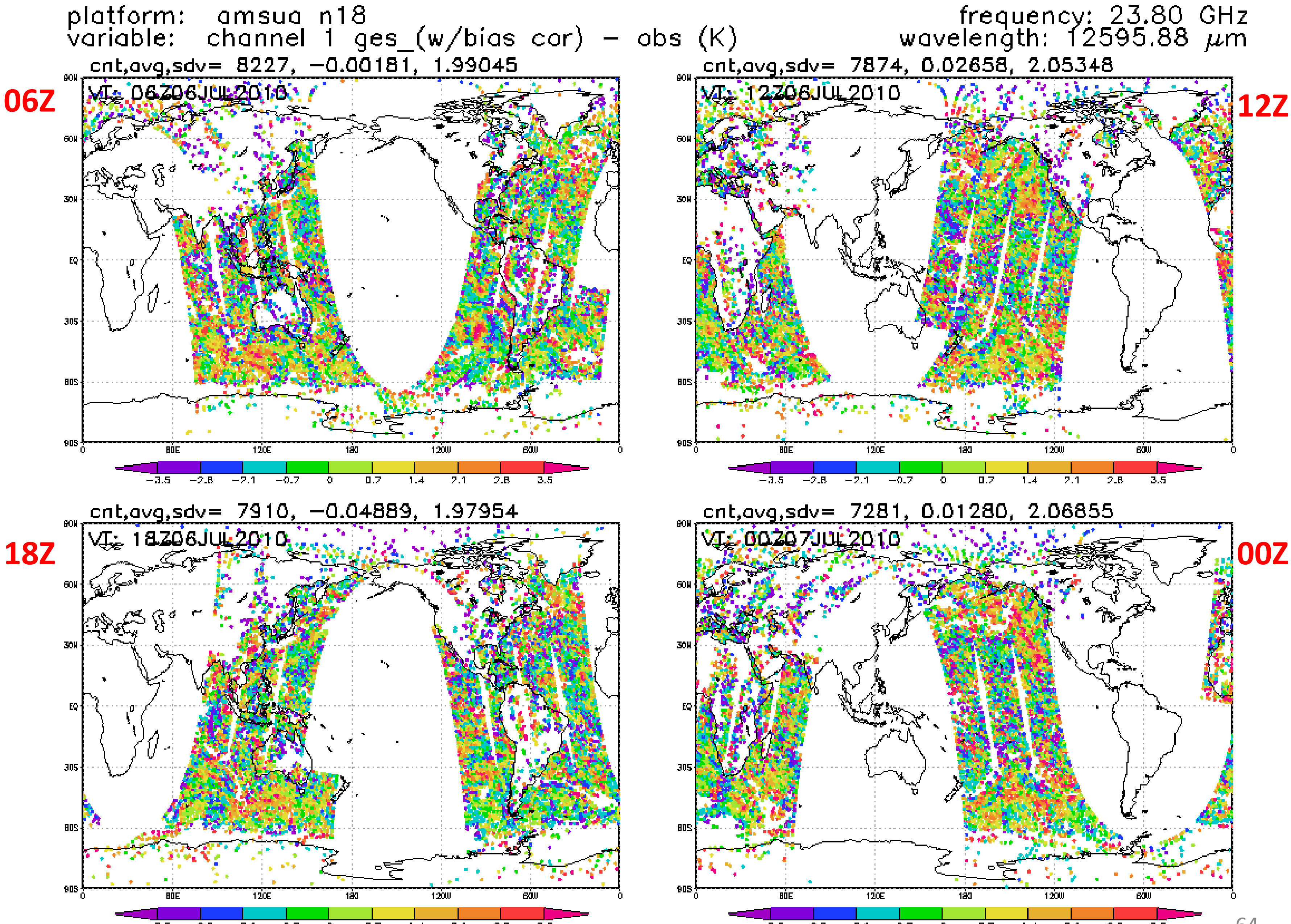
Downwelling radiance at τ_0 ***Upwelling radiance at τ_1***

I_{middle} I_{top} I_{bottom}

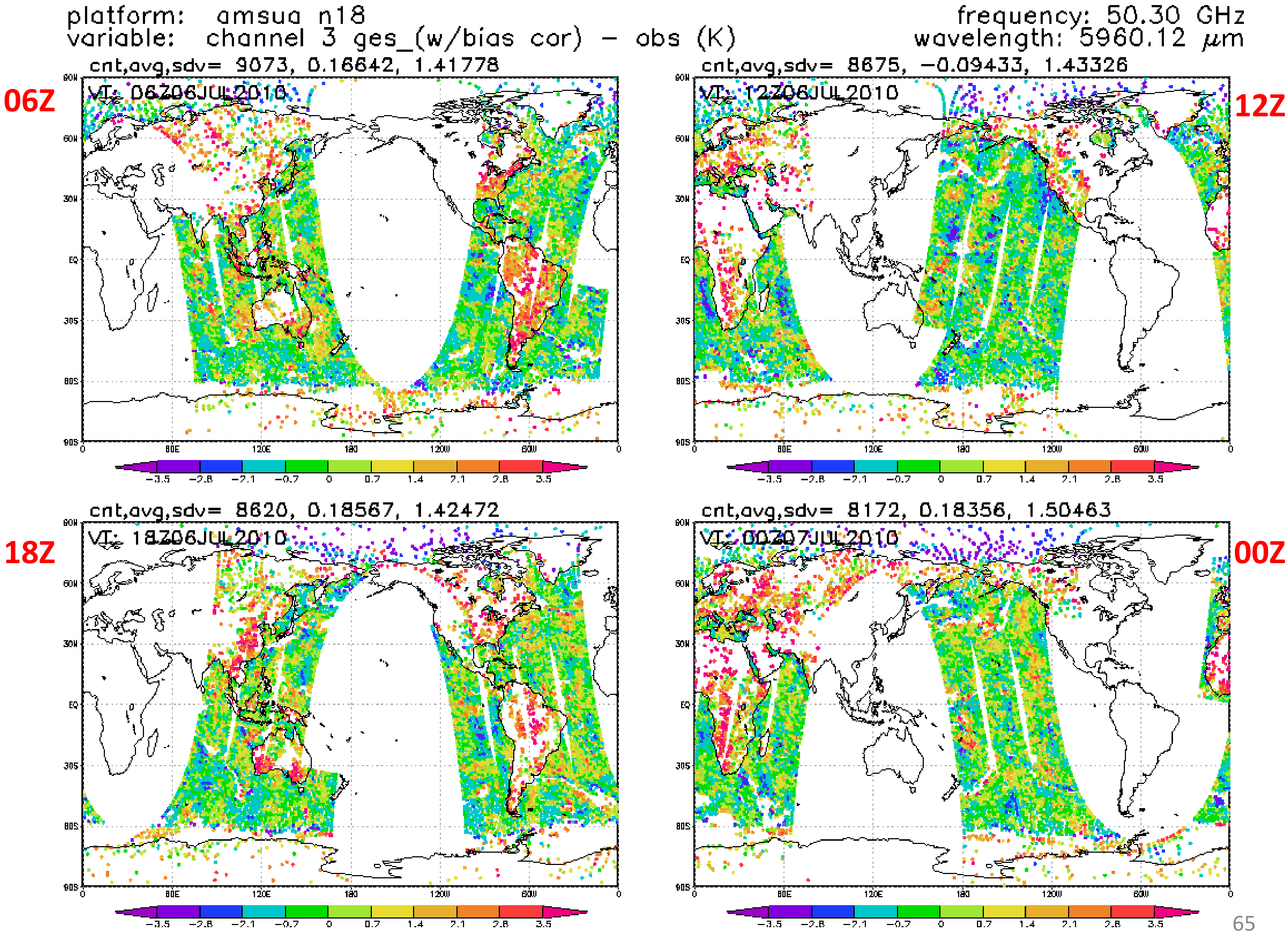
Daytime : $T_g < T_s$, so $I_{bottom} < 0$, $I_t(\tau_0,\mu)$ decreases;

Nighttime: $T_g > T_s$, so $I_{bottom} > 0$, $I_t(\tau_0,\mu)$ increases.

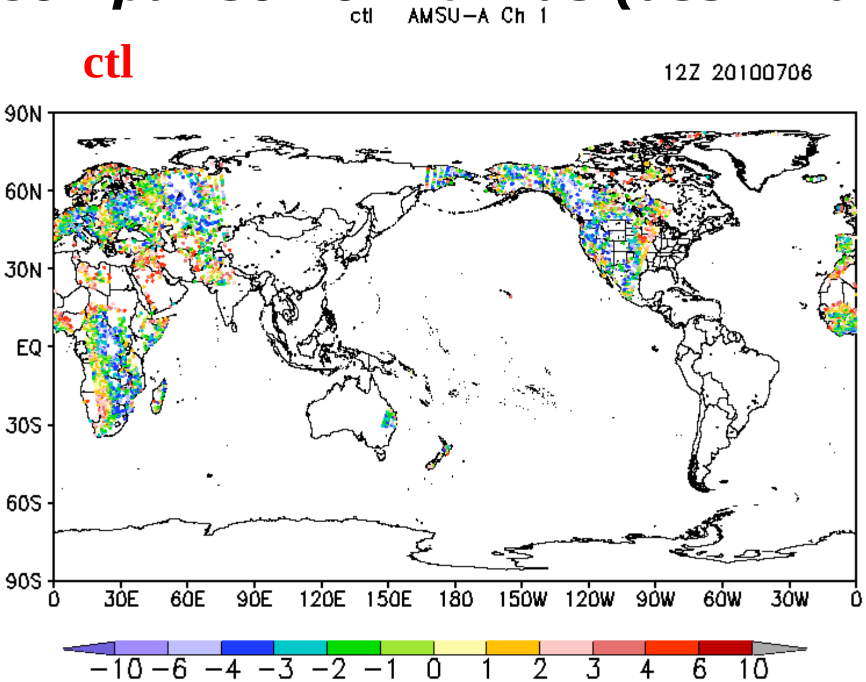
Operational Monitoring Plots: NOAA-18 AMSU-A, Ch1, 06 July 2010

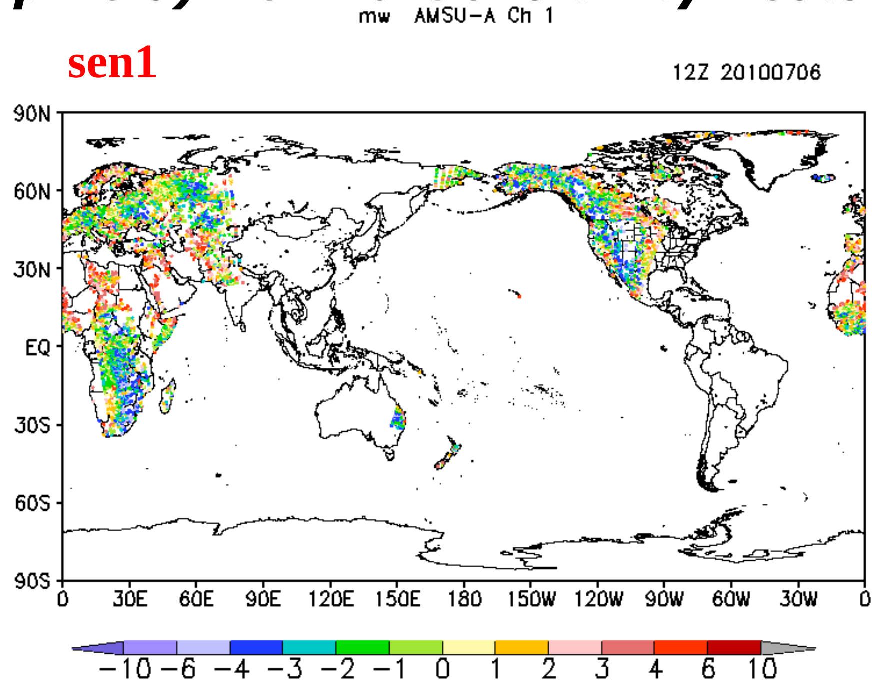


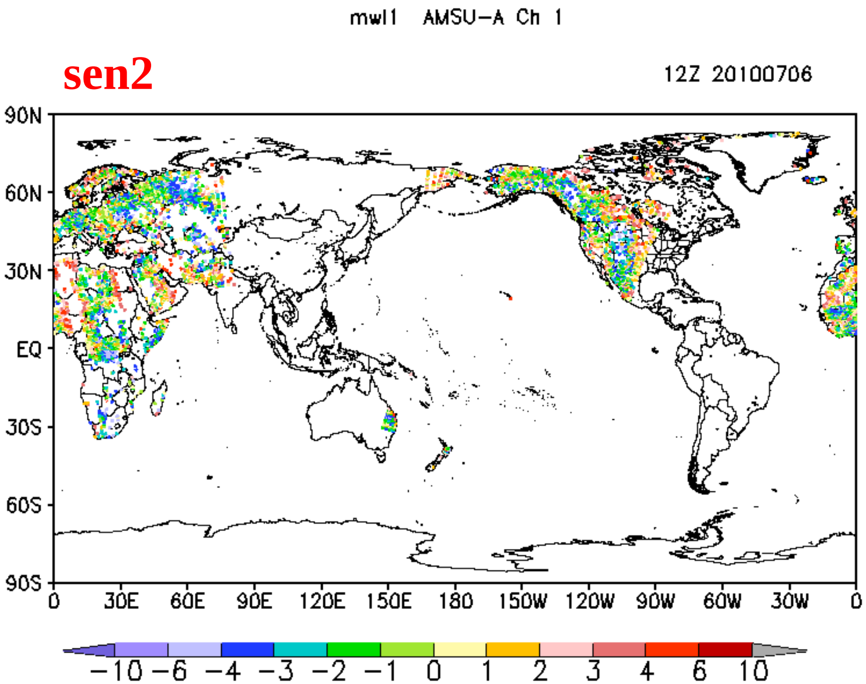
Operational Monitoring Plots: NOAA-18 AMSU-A, Ch3, 06 July 2010



Comparison of Tb Bias (assimilated pixels): CTL & Sensitivity Tests







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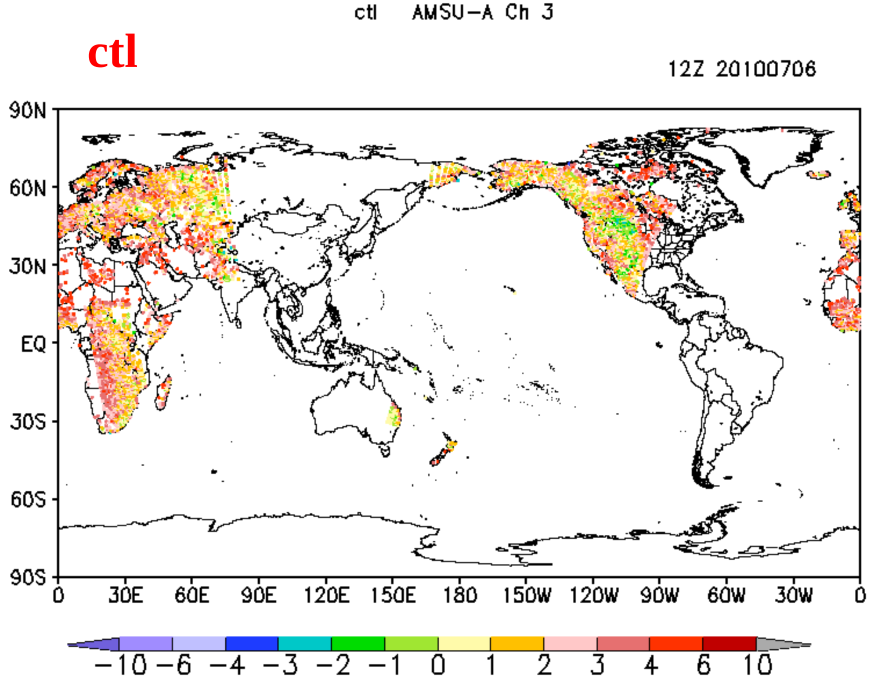

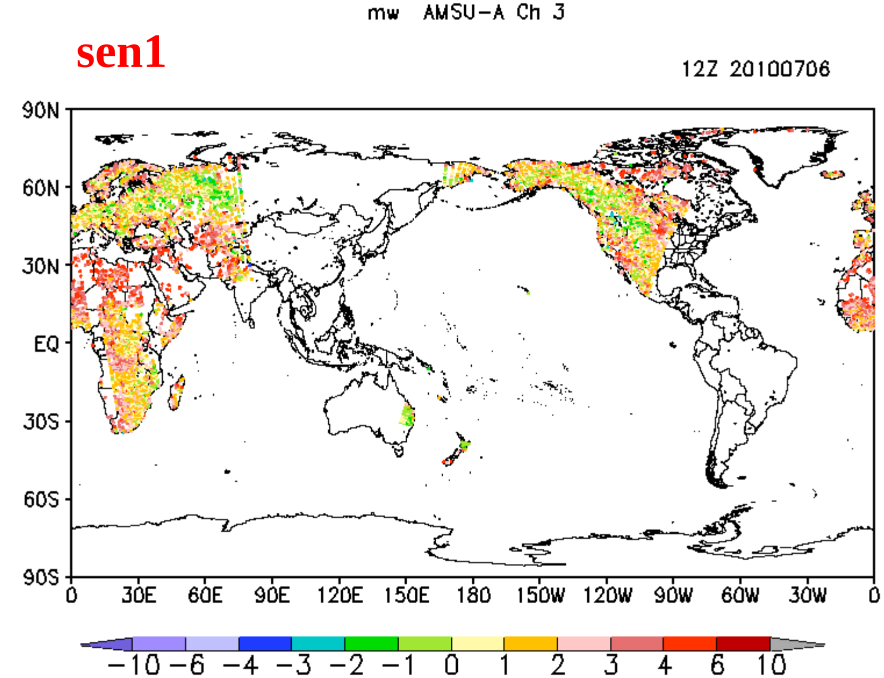

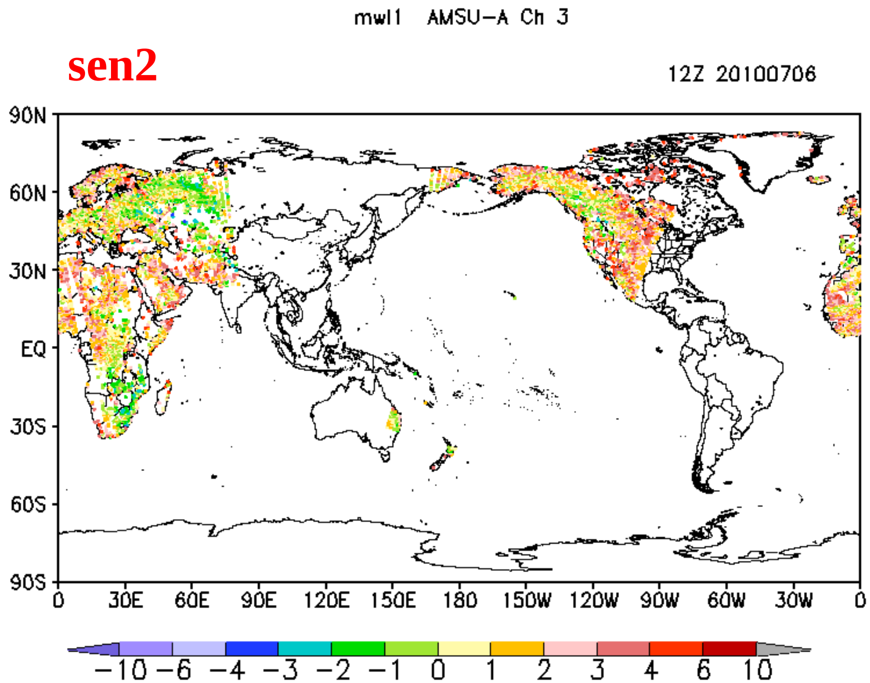

Microwave Land Emissivity Calculation in CRTM summary

• The microwave land surface emissivity model updated with more accurate land surface parameters, canopy optical parameters and alternative dielectric constant calculation.

• Based on the three-layer medium model, the more accurate formula of total upwelling radiance emanating from the surface was derived, considering impact of ground upwelling radiance which is important for low microwave frequency channels, especially for the desert and semi-arid regions.

• **The sensitivity experiments with GSI/CRTM show a reduction of errors in simulated brightness temperature, as well as an increase in the number observations assimilated in the GSI, compared to the results using a previous land surface emissivity scheme.**

• Bias correction needs to further consideration after updated MW land emissivity model. How to consider it?

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  - Soil moisture
  - Snow
- Summary/Future

Recent Land Data Assimilation Results with the Land Information System

Christa Peters-Lidard

Chief, Hydrological Sciences Laboratory, NASA/GSFC

20-MAR-2012

Acknowledgements:

Sujay Kumar, David Mocko – Science Applications International Corporation (SAIC)

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Jim Geiger – Advanced Data Management & Analysis Branch, NASA/GSFC

Ken Harrison, Anil Kumar, Soni Yatheendradas – Earth System Science Interdisciplinary Center, U. of Maryland

Developing Land Data Assimilation Capabilities

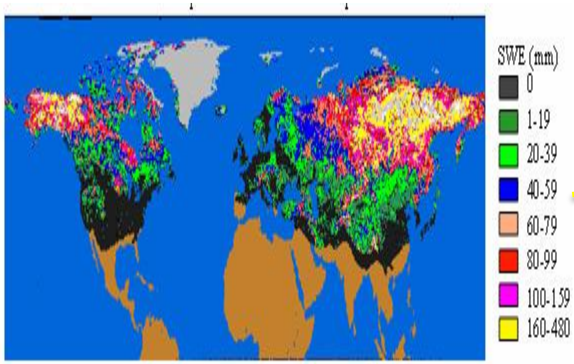
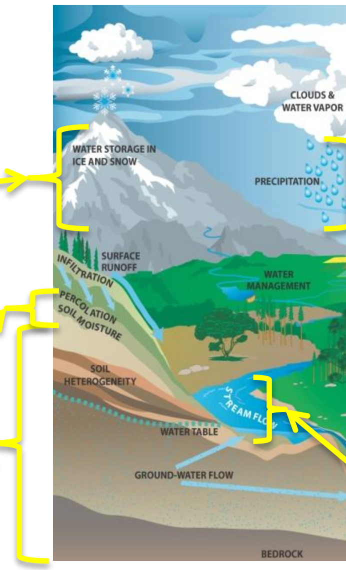


Figure 1: Snow water equivalent (SWE) based on Terra/MODIS and Aqua/AMSR-E. Future observations will be provided by JPSS/VIIRS and DWSS/MIS.



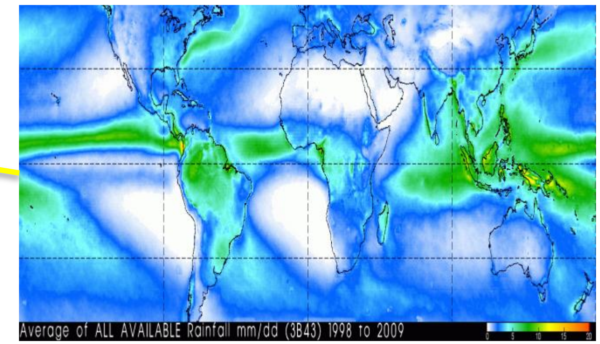


Figure 2: Annual average precipitation from 1998 to 2009 based on TRMM satellite observations. Future observations will be provided by GPM.

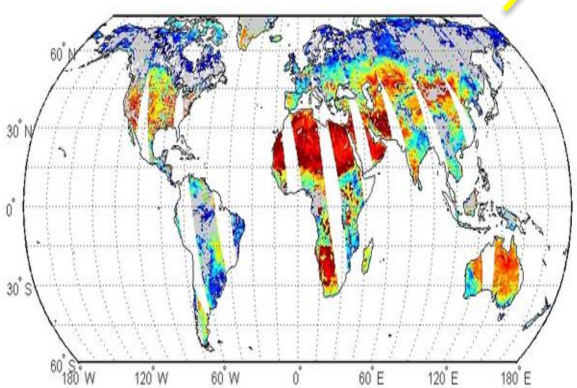


Figure 3: Daily soil moisture based on Aqua/AMSR-E. Future observations will be provided by SMAP.

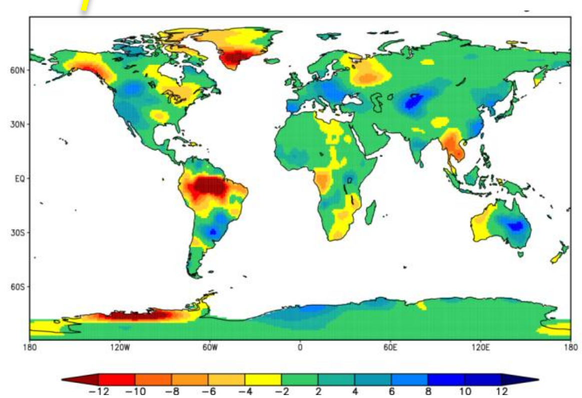


Figure 4: Changes in annual-average terrestrial water storage (the sum of groundwater, soil water, surface water, snow, and ice, as an equivalent height of water in cm) between 2009 and 2010, based on GRACE satellite observations. Future observations will be provided by GRACE-II.

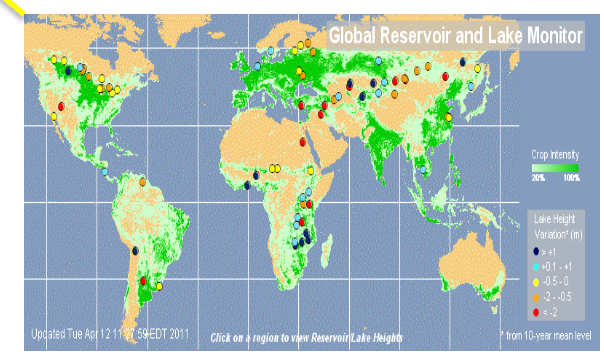
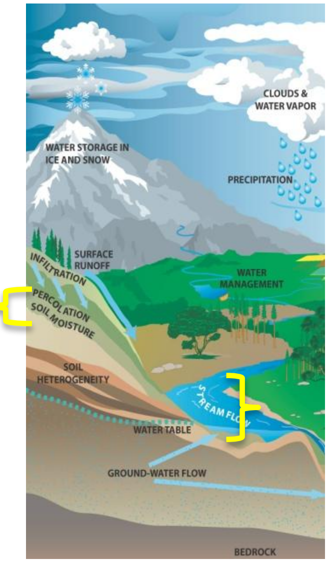


Figure 5: Current lakes and reservoirs monitored by OSTM/Jason-2. Shown are current height variations relative to 10-year average levels. Future observations will be provided by SWOT.

Soil Moisture Data Assimilation



Data Assimilated:

- AMSR-E LPRM soil moisture
- AMSR-E NASA soil moisture

Variables Analyzed:

- Soil Moisture
- Evapotranspiration
- Steamflow

Experimental Setup:

- Domain: CONUS, NLDAS
- Resolution: 0.125 deg.
- Period: 2002-01 to 2010-01
- Forcing: NLDASII
- LSM: Noah 2.7.1,3.2

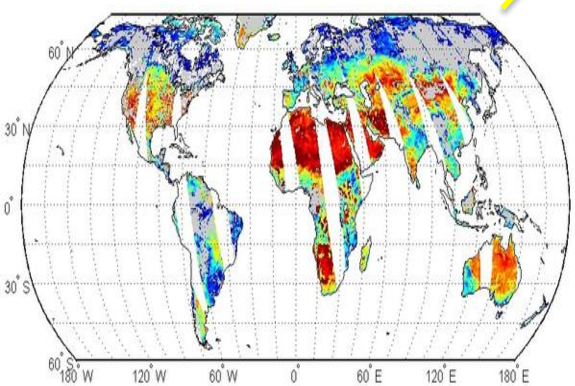
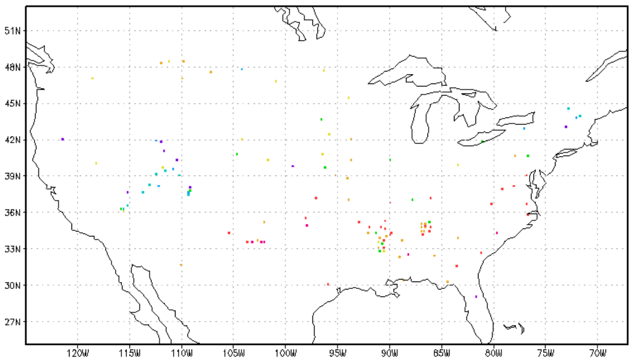


Figure 3: Daily soil moisture based on Aqua/AMSR-E. Future observations will be provided by SMAP.

Peters-Lidard, C.D, S.V. Kumar, D.M. Mocko, Y. Tian, 2011: Estimating evapotranspiration with land data assimilation systems, *Hydrological Processes*, 25(26), 3979--3992, DOI: 10.1002/hyp.8387

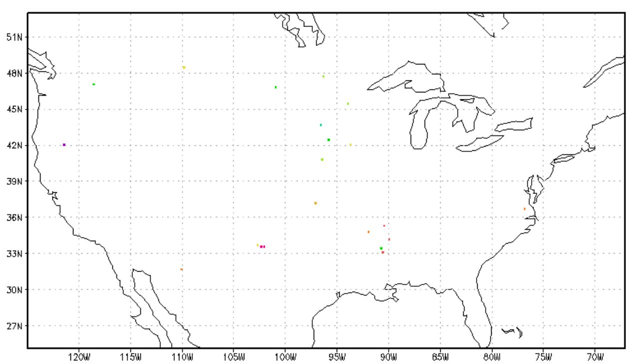
Soil moisture Assimilation -> soil moisture (Evaluation vs SCAN)

ALL available stations (179)



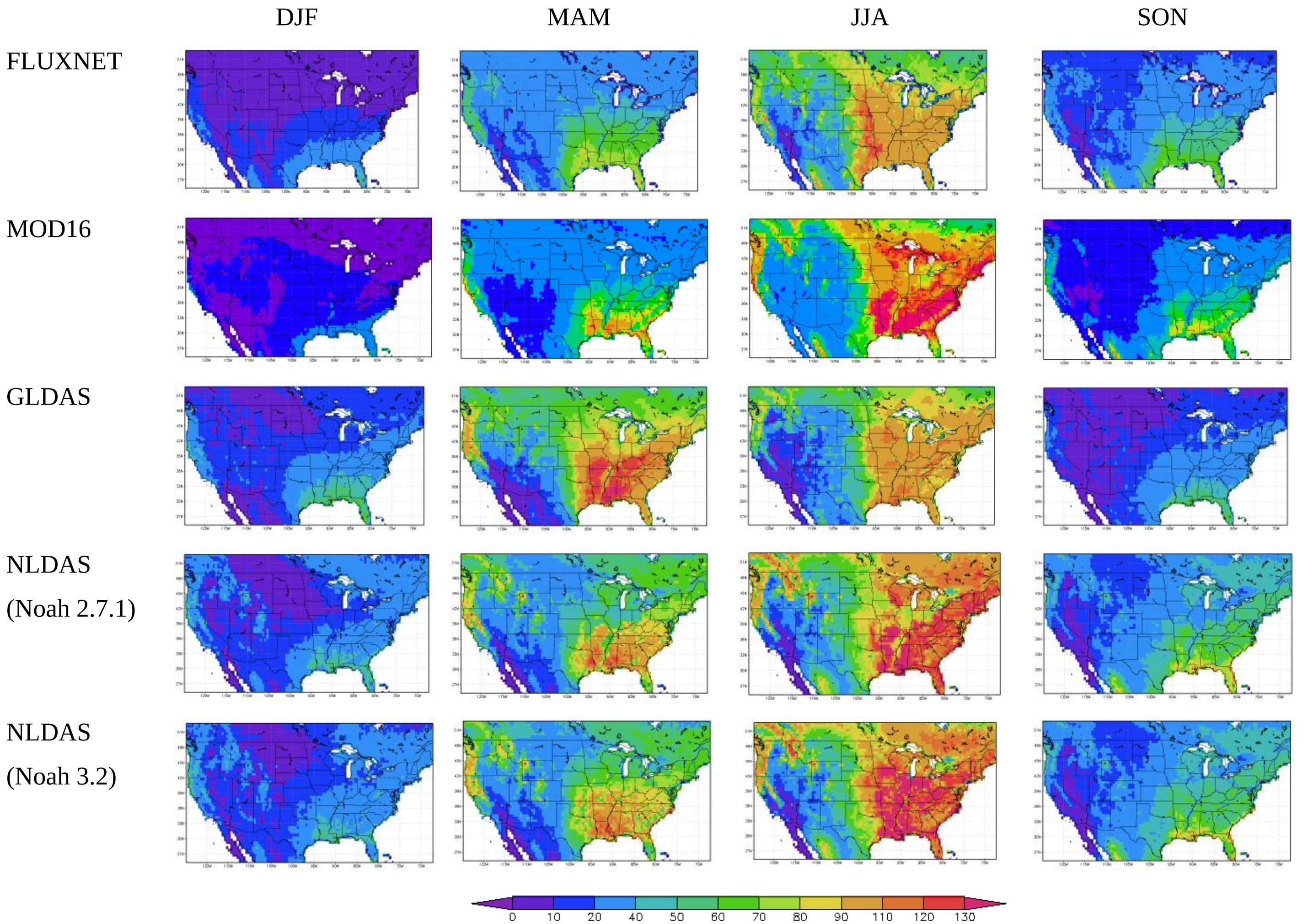
Anomaly correlation	OL	NASA-DA	LPRM-DA
Surface soil moisture (10cm)	0.55 +/- 0.01	0.49 +/- 0.01	0.56 +/- 0.01
Root zone soil moisture (1m)	0.17 +/- 0.01	0.13 +/- 0.01	0.19 +/- 0.01

(21) Stations listed in Reichle et al. (2007)



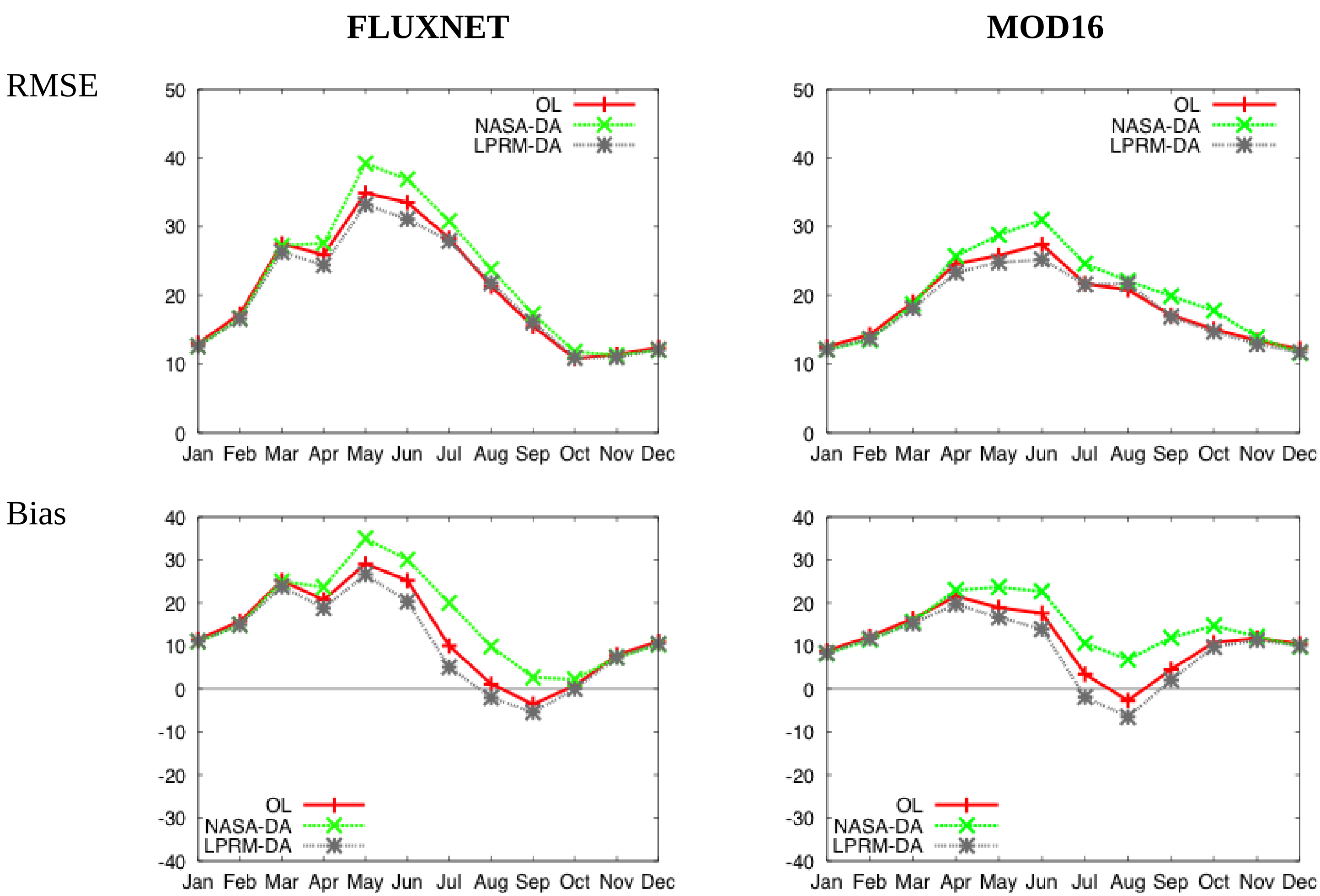
Anomaly correlation	OL	NASA-DA	LPRM-DA
Surface soil moisture (10cm)	0.62 +/- 0.05	0.53 +/- 0.05	0.62 +/- 0.05
Root zone soil moisture (1m)	0.16 +/- 0.05	0.13 +/- 0.05	0.19 +/- 0.05

Latent Heat Flux (Qle) Estimates over CONUS (“Observed” vs. Modeled Open Loop (OL))



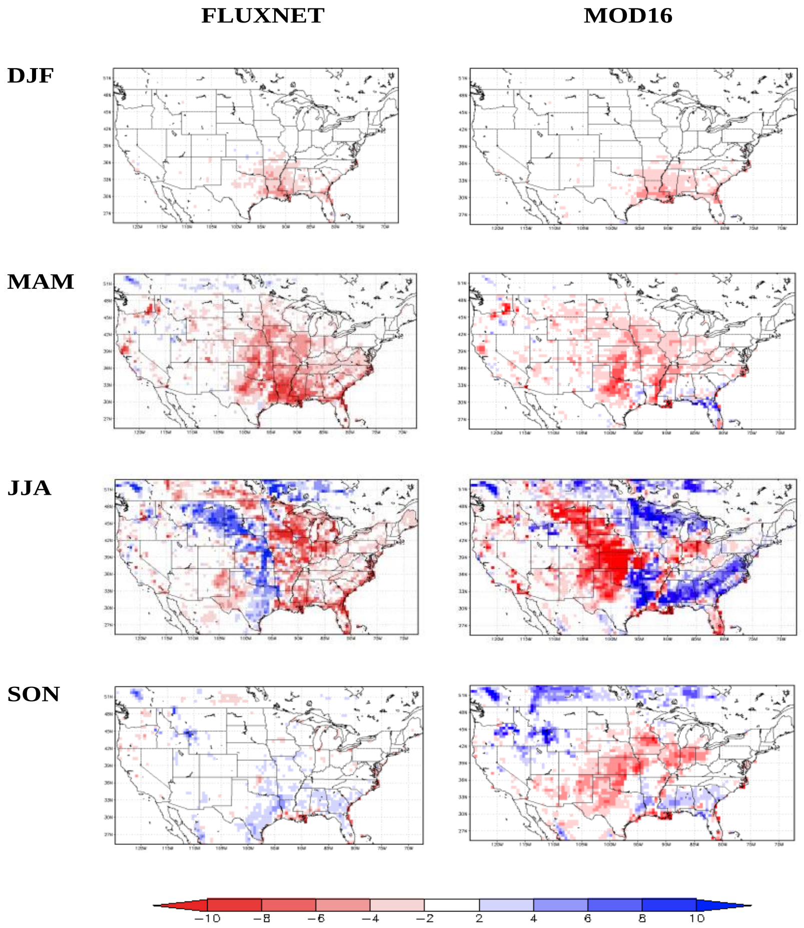
Peters-Lidard, C.D, S.V. Kumar, D.M. Mocko, Y. Tian, 2011: Estimating evapotranspiration with land data assimilation systems, *Hydrological Processes*, 25(26), 3979--3992, [DOI: 10.1002/hyp.8387](DOI: 10.1002/hyp.8387)

Soil Moisture Assimilation -> Evapotranspiration (Qle)

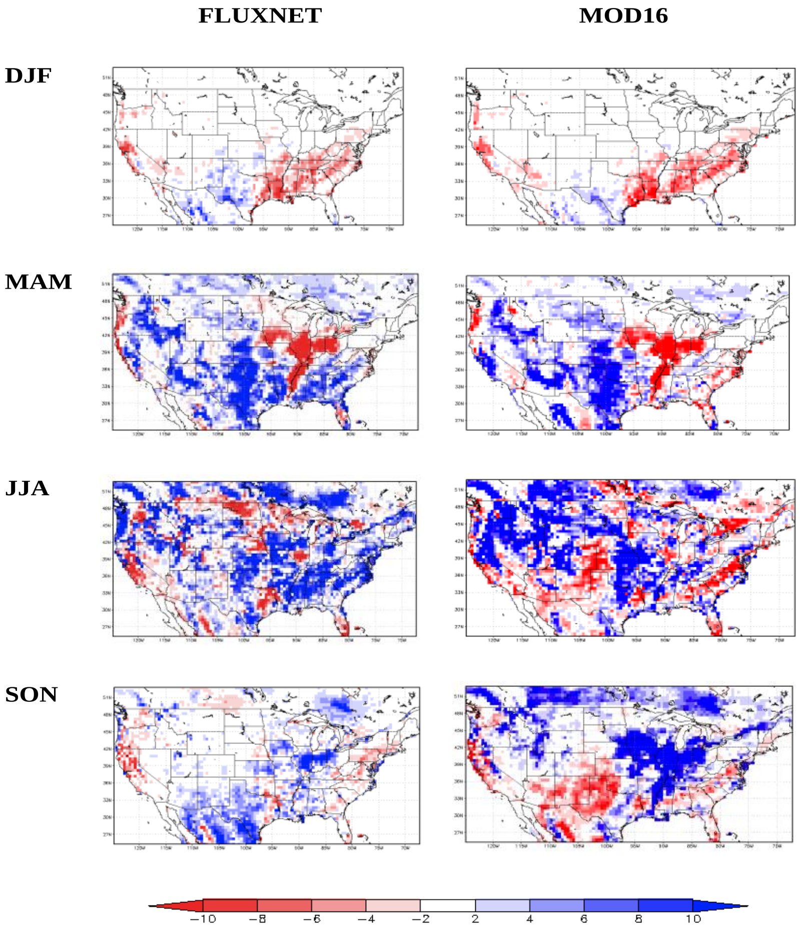


Peters-Lidard, C.D, S.V. Kumar, D.M. Mocko, Y. Tian, 2011: Estimating evapotranspiration with land data assimilation systems, *Hydrological Processes*, 25(26), 3979--3992, [DOI: 10.1002/hyp.8387](https://doi.org/10.1002/hyp.8387)

Where Does Soil Moisture Assimilation Help Improve Qle (i.e. Reduce RMSE) ?



LPRM-DA



NASA-DA

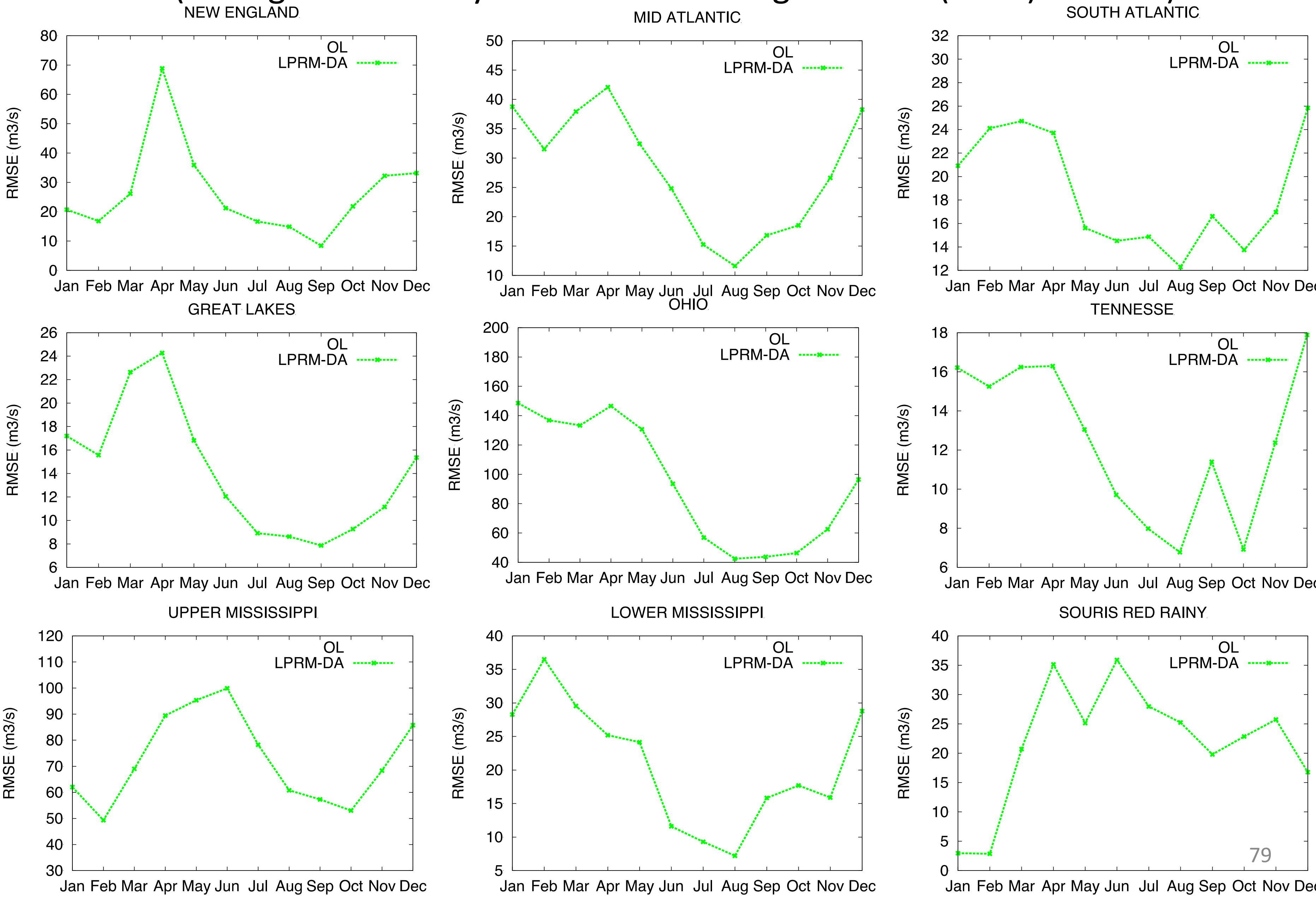
Peters-Lidard, Christa D., Sujay V. Kumar, David M. Mocko and Yudong Tian, (2011), Estimating Evapotranspiration with Land Data Assimilation Systems, In press, *Hyd. Proc*.

Where Does Soil Moisture Assimilation Help Improve Qle (i.e. Reduce RMSE) ?

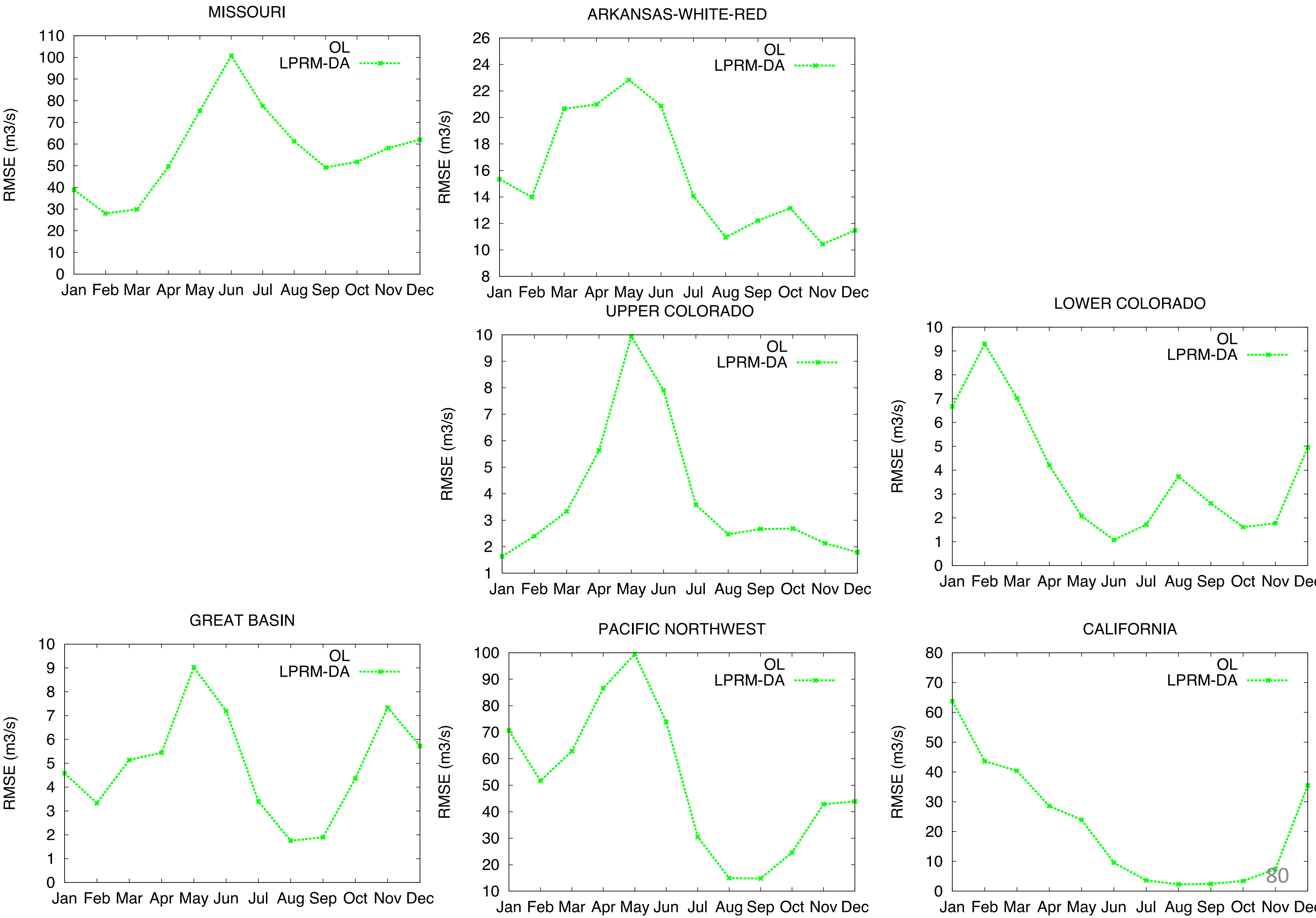
Qle RMSE % Difference (DA-OL)	FLUXNET		MOD16	
Landcover type	**NASA-DA (Wm^{-2})**	**LPRM-DA (Wm^{-2})**	**NASA-DA (Wm^{-2})**	**LPRM-DA (Wm^{-2})**
Evergreen needleleaf forest	17.6	7.9	10.5	-3.6
Deciduous broadleaf forest	3.2	12.7	0.3	0.7
Mixed forest	1.8	8.0	-0.7	-0.9
Woodlands	16.4	18.9	11.5	-5.9
Wooded grassland	8.8	-0.5	9.6	0.3
Closed shrubland	7.3	3.4	2.5	8.9
Open shrubland	9.0	7.4	3.6	12.1
Grassland	23.9	7.1	32.9	46.4
Cropland	12.3	34.7	30.9	40.8
Bare soil	-0.1	0.6	-0.8	1.4
Urban	-0.1	-0.1	-0.2	-0.3

Soil Moisture Assimilation -> Streamflow Evaluation vs. USGS gauges – by major basins

Soil Moisture Assimilation -> Streamflow (average seasonal cycles of RMSE– using Xia et al. (2011) stations)



Soil Moisture Assimilation -> Streamflow
(average seasonal cycles of RMSE– using Xia et al. (2011) stations)



SMOS soil moisture assimilation tests in the GFS

- The simplified ensemble Kalman Filter (EnKF) was embedded in the GFS latest version to assimilate soil moisture observation
- Case: 00Z July 6, 2011. (GFS free forecast)
- Experiments:

  CTL: Control run

  EnKF: Sensitivity run

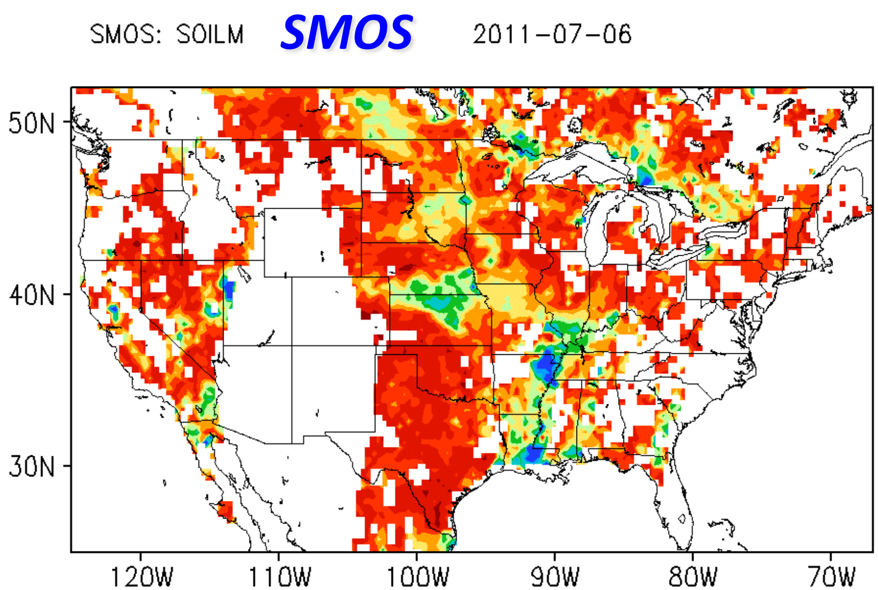
  (PRT: 0.20, 0.15, 0.10, 0.05)

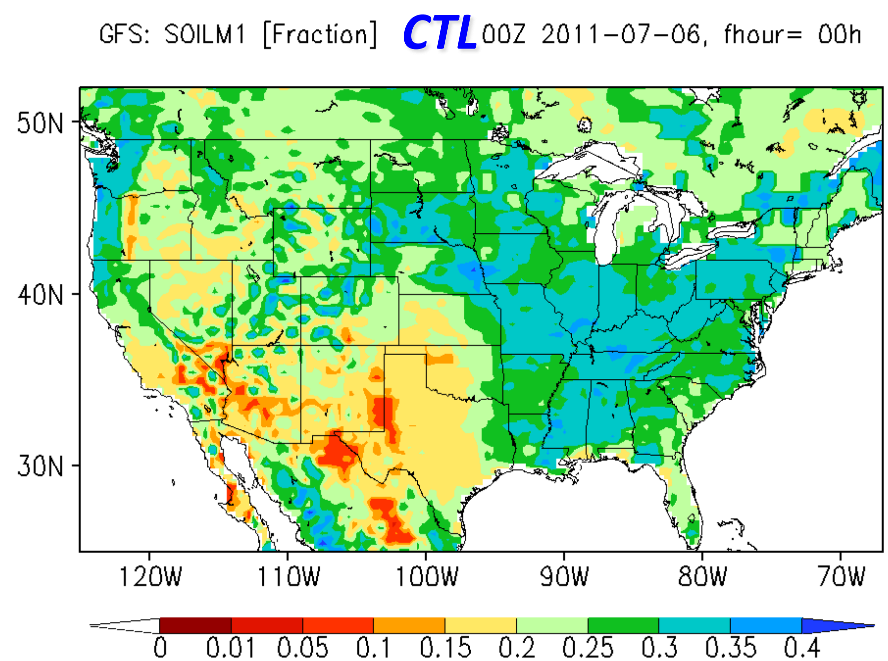
  and precipitation perturbation.

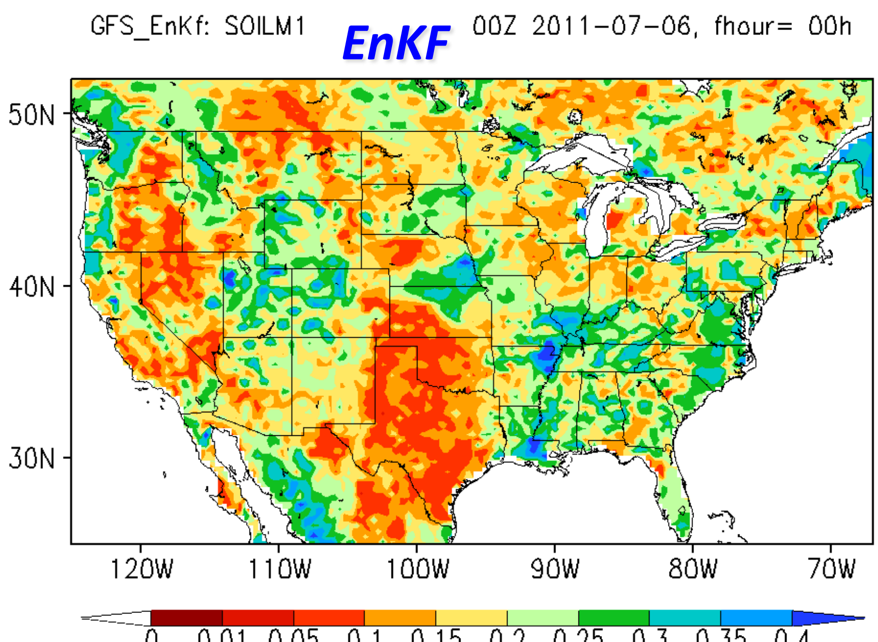
PRT: Perturbation size for each layer soil moisture.

Weizhong Zheng and Xiwu Zhan (NESDIS/STAR)

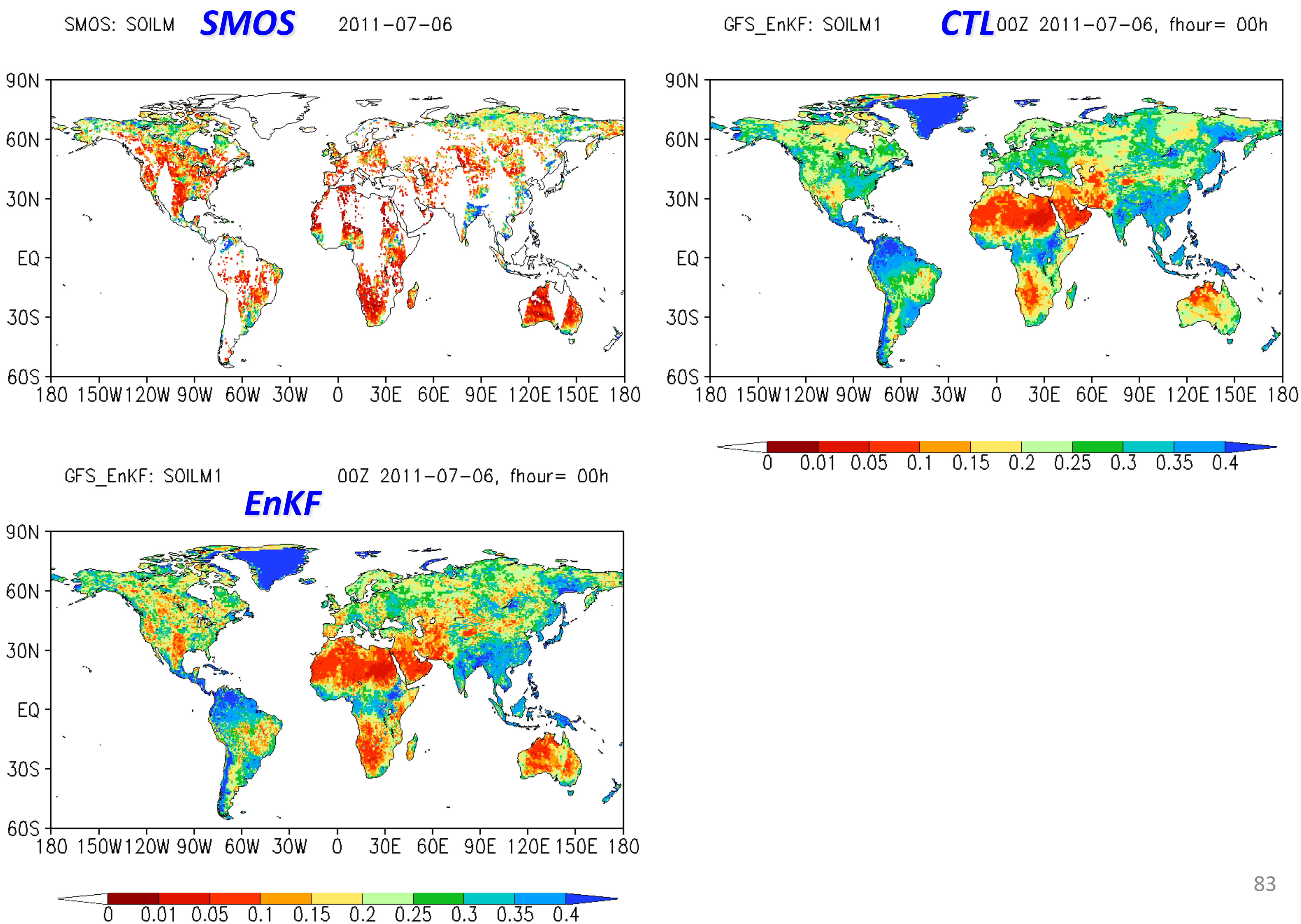
Comparison of Soil Moisture between GFS & SMOS



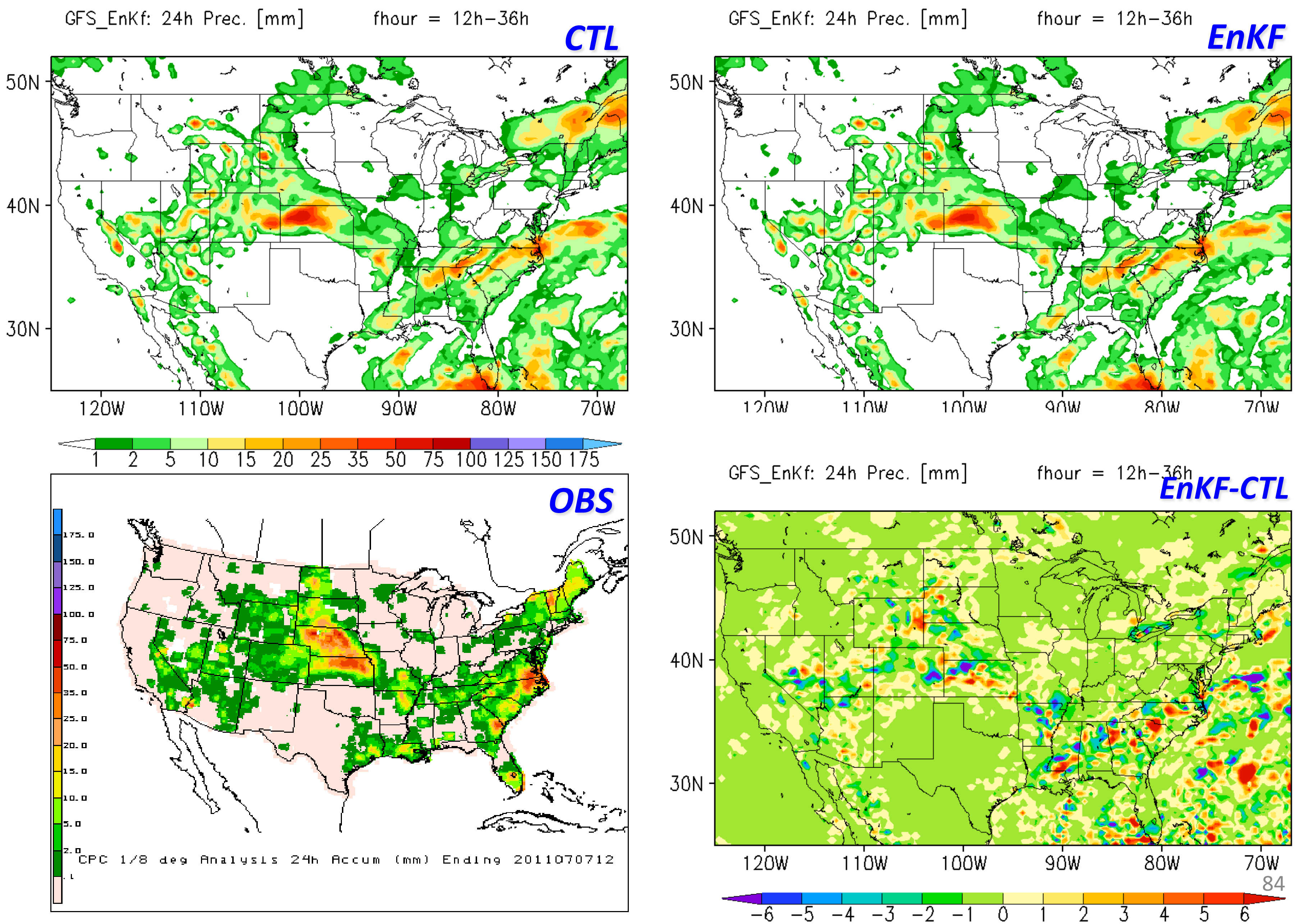


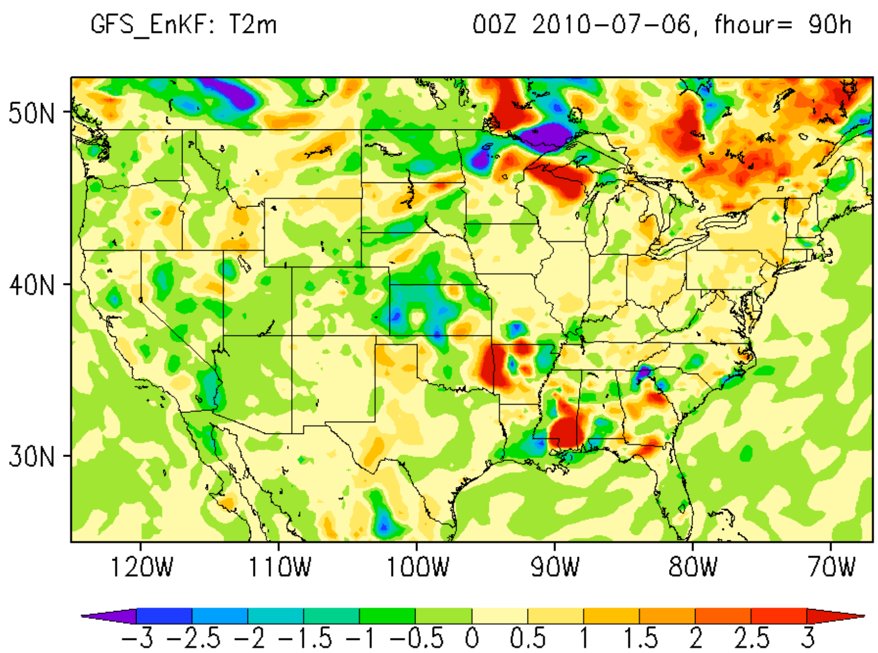


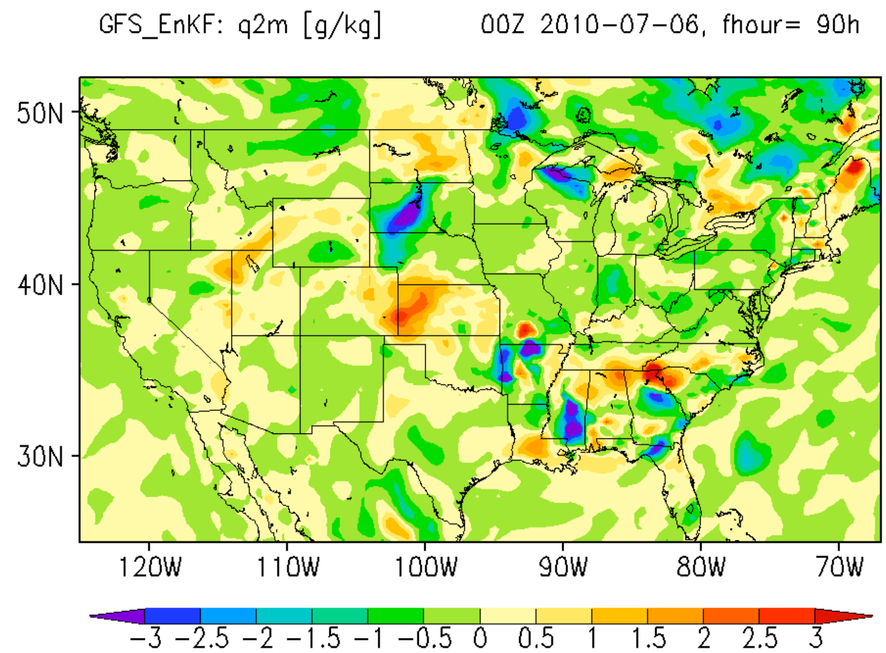
Comparison of Soil Moisture between GFS & SMOS

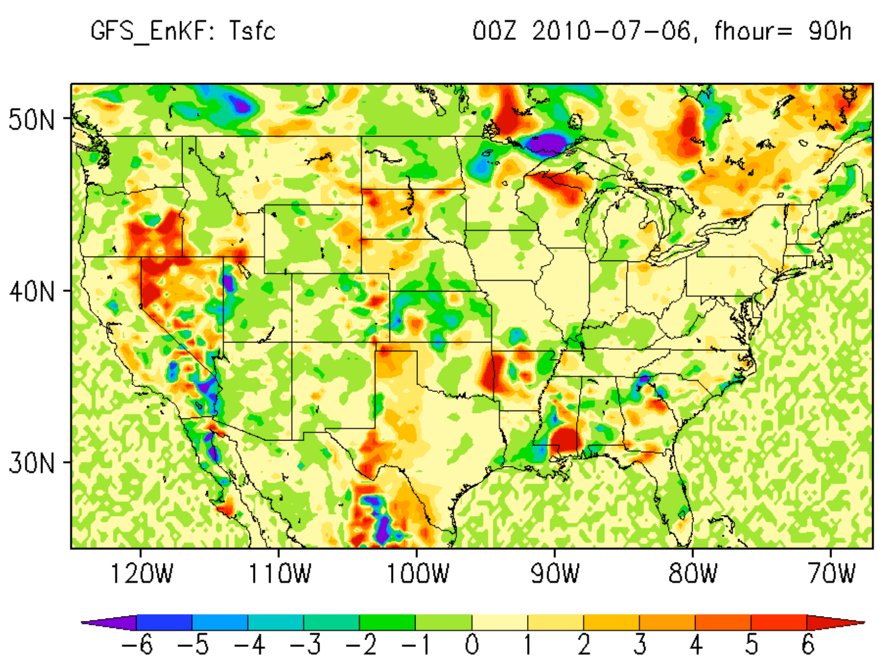


Comparison of Precipitation between CTL and EnKF

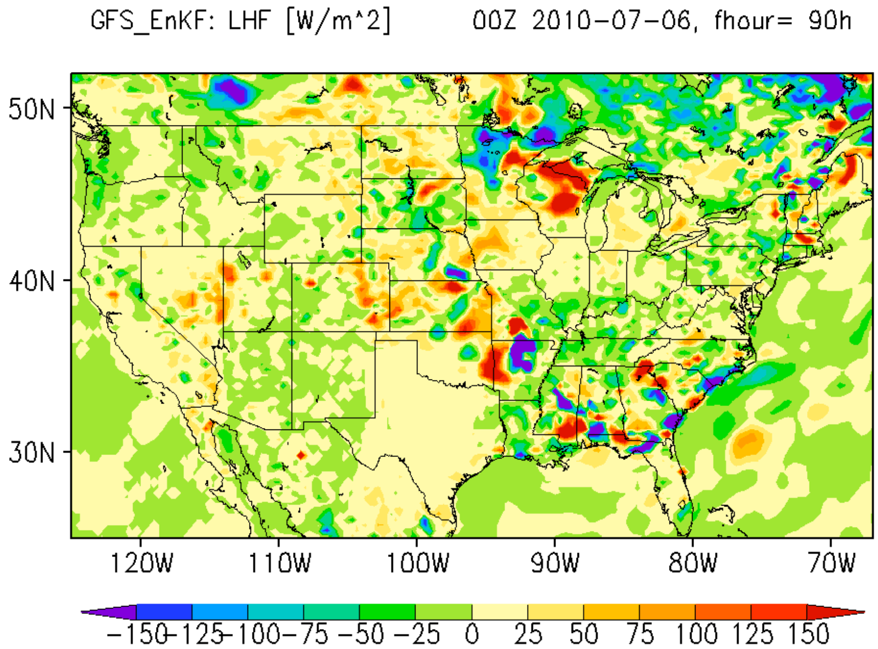


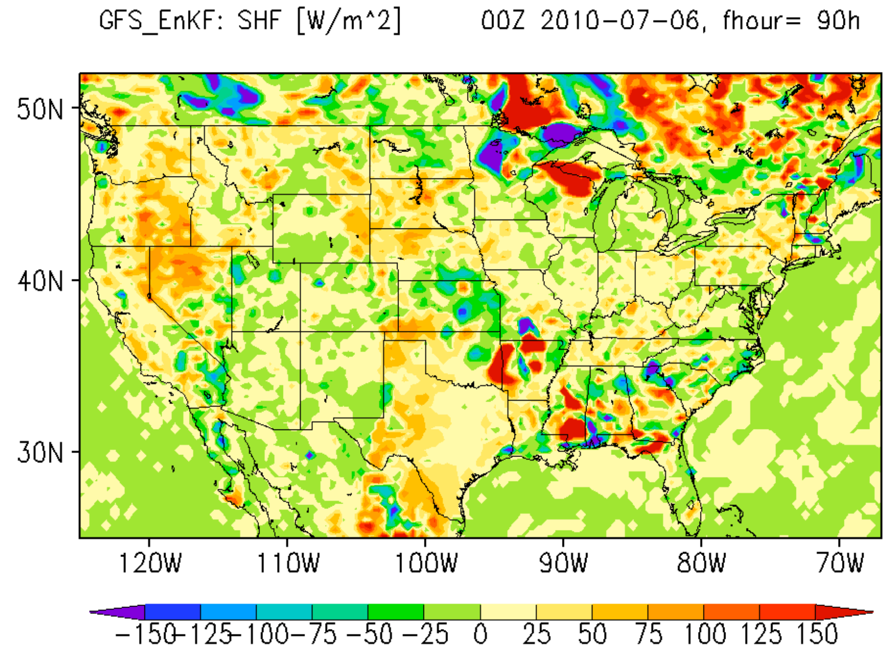






Difference of T2m, q2m and Tsfc between CTL and EnKF at 90h (daytime in central US)





Difference of latent heat flux (LHF) and sensible heat flux (SHF) between CTL and EnKF at 90h (daytime in central US)

Outline

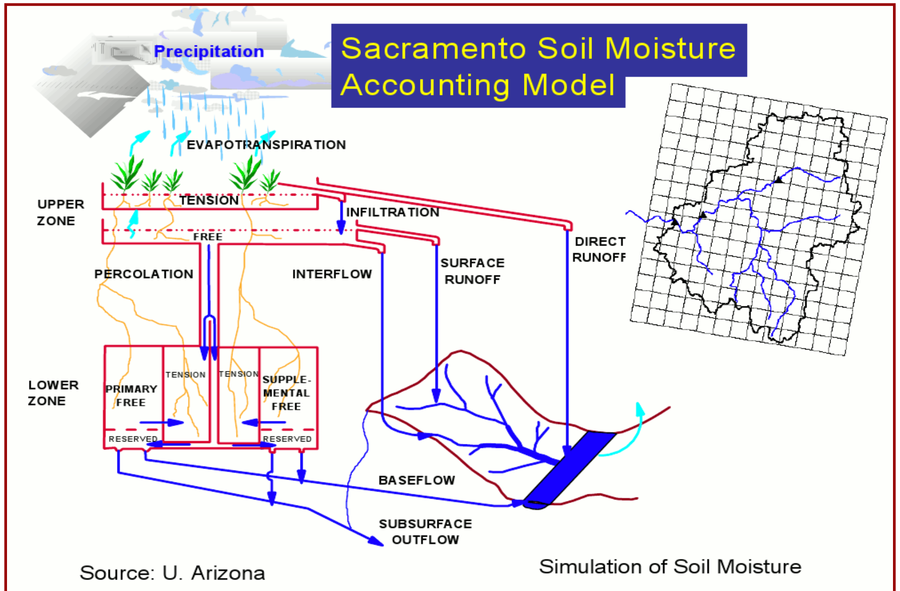
- Motivation
- Applications:
  - North American Land Data Assimilation System (NLDAS) -- “Flagship” LDAS project at NCEP
  - “HRAP”-NLDAS
  - Global LDAS (GLDAS)
- Methods/examples:
  - Surface emissivity/Tb assimilation
  - Soil moisture
  - Snow
- Summary/Future

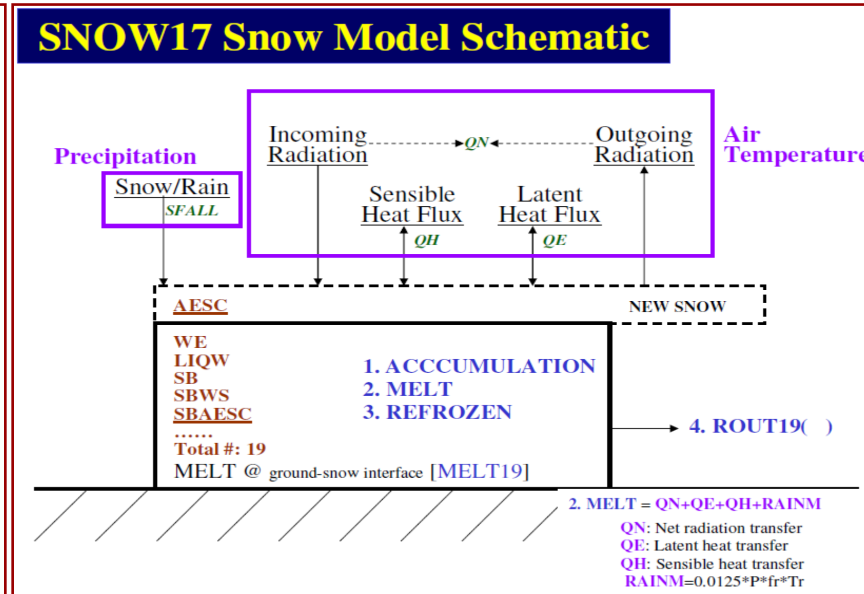
Assimilation of MODIS snow

Motivation

- In the western United States, over half of the water supply is derived from mountain snowmelt.
- In many mid latitude and high altitude regions, the snow delays runoff and provides water in the spring and summer when it is needed most.
- Both the passive microwave snow water equivalent (SWE) observations and model predictions contain large errors due to land surface complexities.
- Accurate knowledge of snowpack properties is important for short-term weather forecasts, climate change prediction, and hydrologic forecasting.

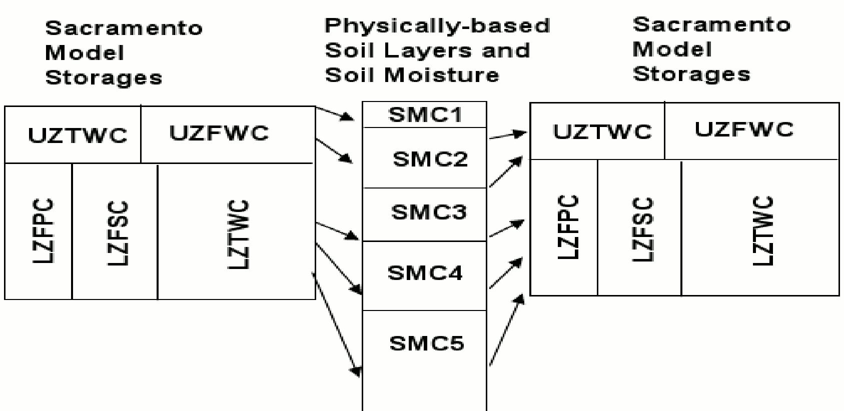
Models





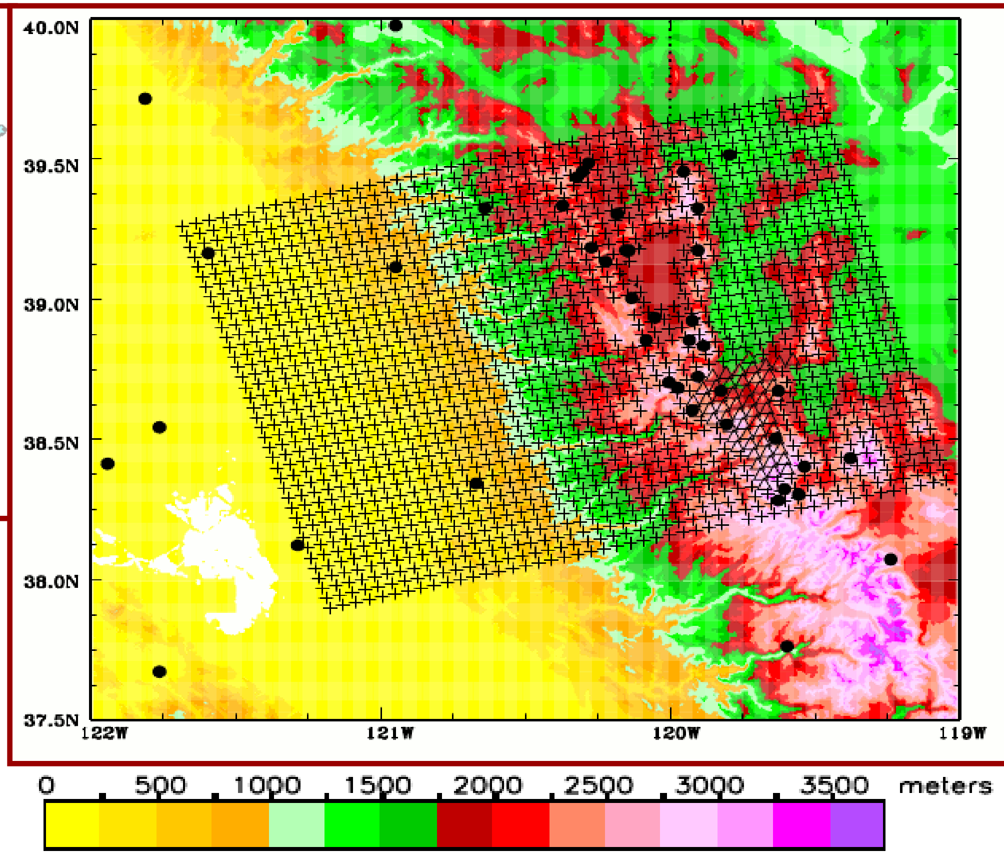
SAC-HT

In each grid and in each time step, transform *conceptual* soil water content to *physically-based* water content



Study Domain

DMIP2 West - American, Carson



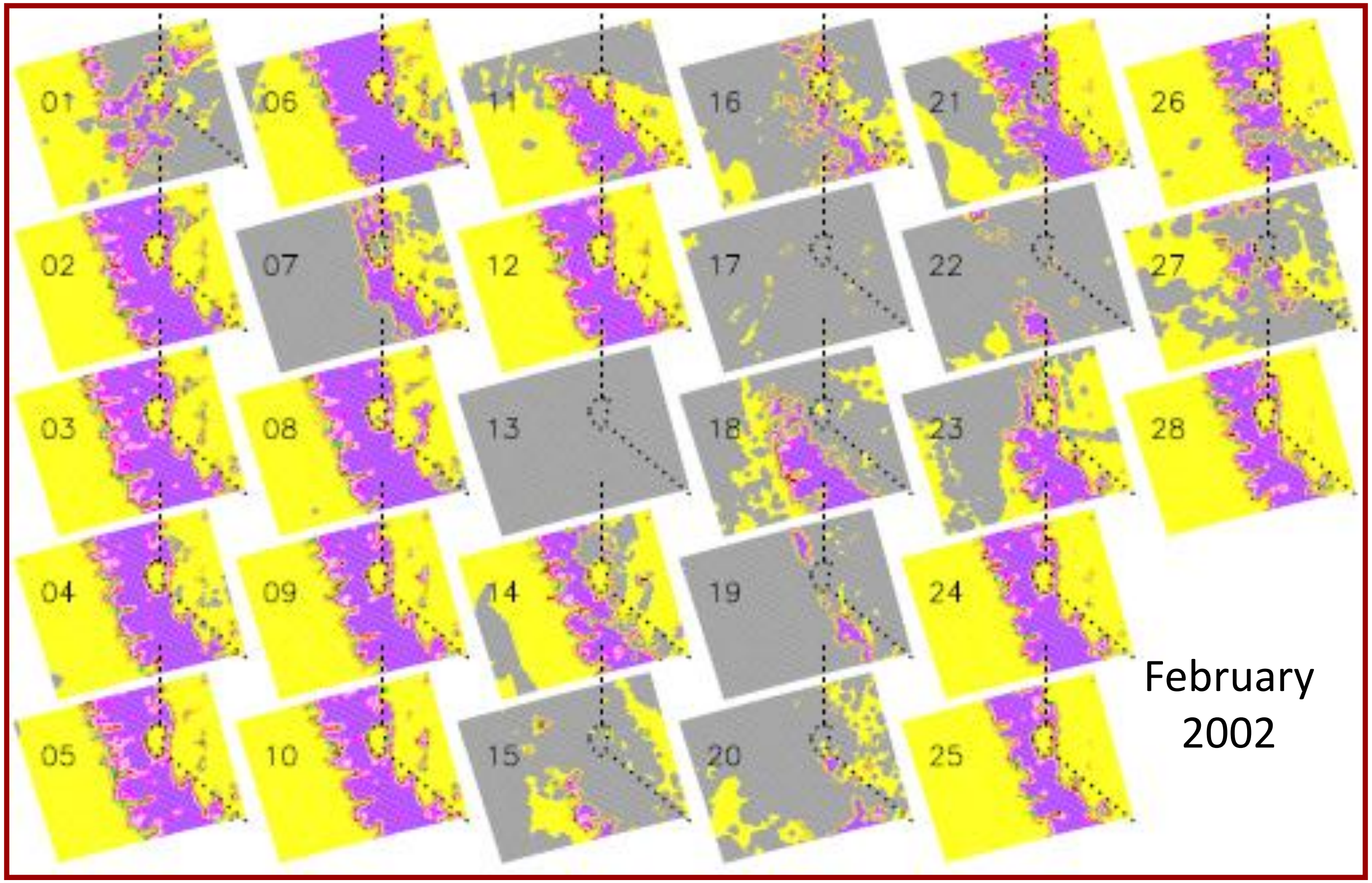
Sierra-Nevada Basins

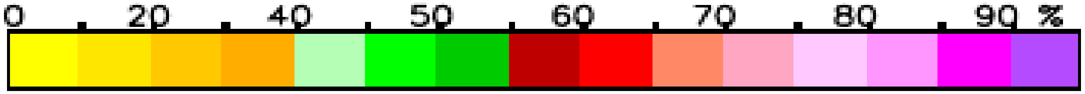
PLUSES — DMIP2 Sierra-Nevada Basin in HRAP grid (48×39 grids)

TRIANGLES – East Fork Carson River Basin grid (9×13 grids)

DOTS — SNOTEL & USHCN in-situ sites.

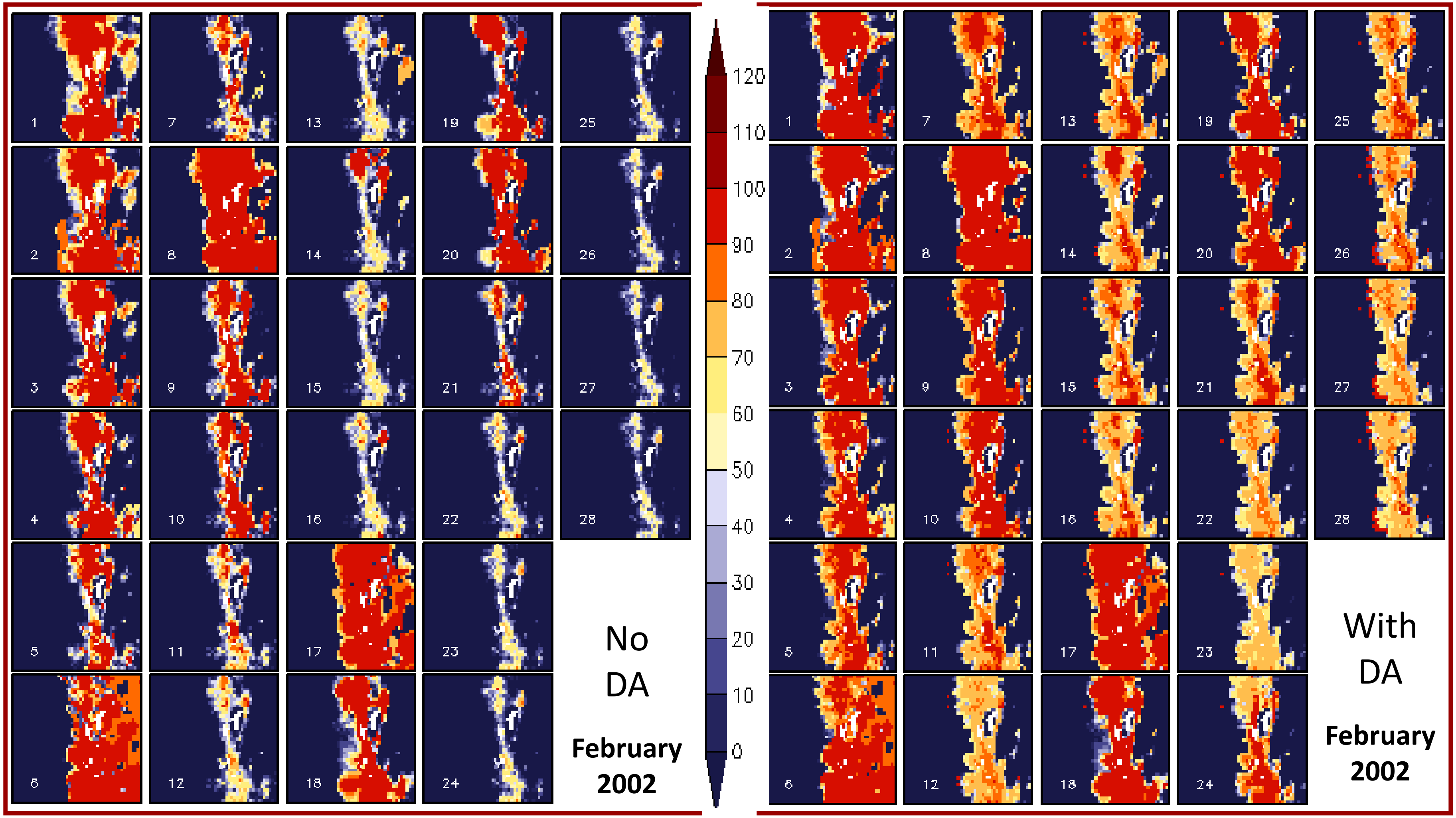
MODIS Snow Cover Frac on HRAP grid





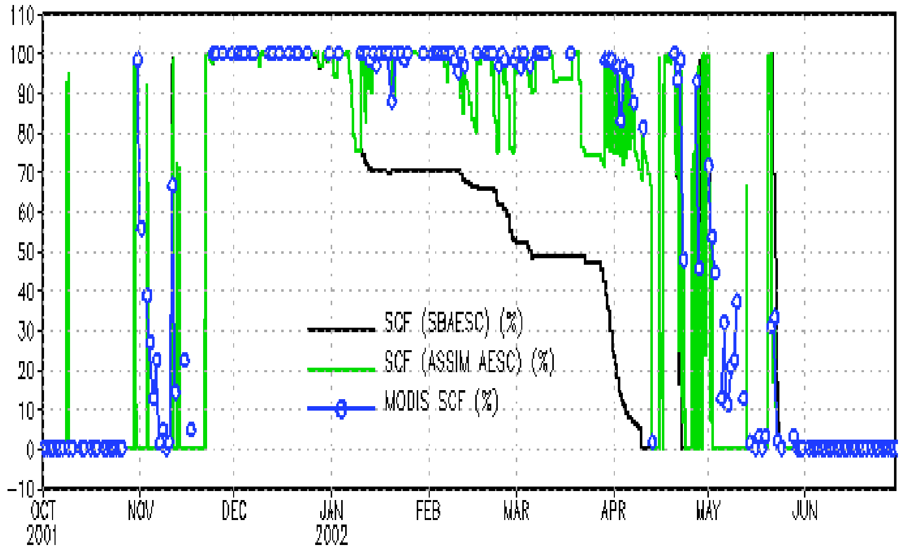
The snow cover fraction data were derived from Terra-MODIS Level 3 500m Daily Snow Cover Area Data onto a HRAP grid at 4.7625KM resolution. The HRAP grid is treated as cloud cover when the cloud cover fraction is above 50%.

Data Assimilation (spatial comp.)



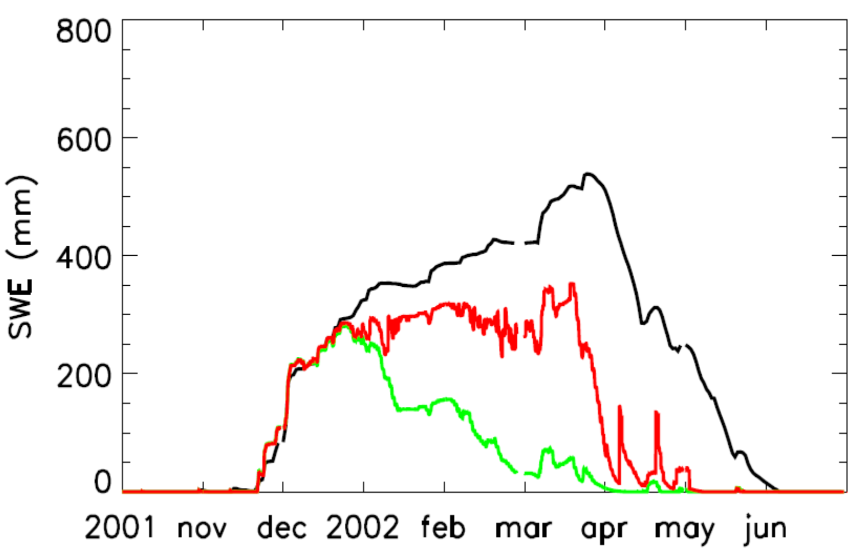
We perform two runs in parallel. One without assimilation (left), the other applying data assimilation (right). We just apply the direct insertion algorithm in our assimilation. LIS SAC-HT/SNOW17 model operates 1 Oct 2001 to 30 Sep 2002.

Data Assimilation (temporal comp.)



Snow Cover Fraction

Comparison of snow cover fraction between the MODIS (blue circles), the open loop simulation (black line) and the assimilation simulation (green line).



Snow Water Equivalent

Comparison of snow water equivalent between the open loop simulation (green), the assimilation simulation (red) and the in-situ measurement (black) averaged over all SNOTEL sites in the study region.

Snow Assimilation Summary and Future Plans

- This study has investigated remotely-sensed MODIS snow cover estimation uncertainty. For cloud-free pixels, the MODIS SCA retrieval errors can be quantitatively predicted by temperature with regional calibrated parameters.
- The preliminary experiments show that the snow cover fraction after assimilation shows close agreement to the MODIS SCF observations.
- Comparison at an individual grid between open loop and assimilation simulations shows that the snow water equivalent is also modified through assimilation of MODIS SCF.
- We will apply the derived statistical regression equation to prescribe the error in MODIS snow cover fraction, and further apply into the EnKF assimilation.

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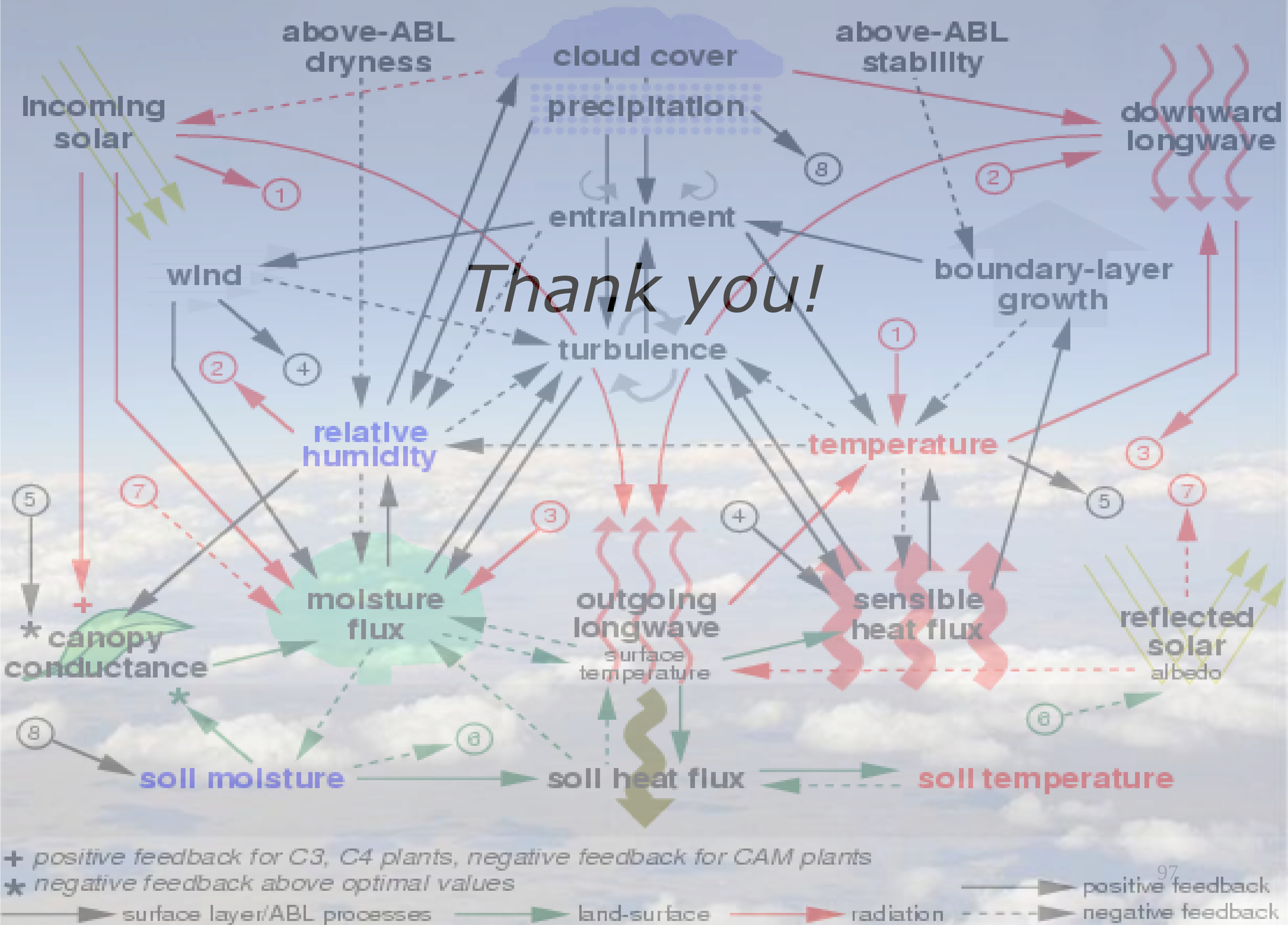
NCEP/EMC Land Modeling and Data Assimilation: Future – <u>Big Picture</u>

- Unified Noah LSM in all NCEP NWP and climate systems, plus in **NLDAS/GLDAS**.
- Noah land model run in **GLDAS under NASA/LIS** as part of the NOAA Environmental Modeling System (NEMS). Currently LIS used in CFS/GLDAS, and in uncoupled NLDAS & HRAP-NLDAS.
- **Assimilation of land states,** e.g. snow, soil moisture, skin temperature, vegetation.
- **Multi-land model ensemble** under NEMS/LIS.
- What we learn here will help **improve model physics** in Noah (and other land models) and ancillary codes (e.g. surface-layer); **use LIS LVT**.

land-surface - ABL - radiation interactions



Thank you!